



**PHYSICS IS FUN**  
*Jardine*  
**BOOK ONE**

# Physics

IS FUN

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*By the same author*

Physics is Fun, Volume Two

Physics is Fun, Volume Three

Physics is Fun, Volume Four

# Physics

## IS FUN

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*An introductory course for secondary schools in four volumes*

### BOOK ONE

by **Jim Jardine**, *B.Sc., B.Ed., A.Inst.P.*

*Head of the Physics Department, George Watson's College, Edinburgh*

*Illustrated by Geoffrey Salter*



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# Preface (adults only)

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## Contents

This book covers the first year's work of a Secondary School physics course, following the order of the New Scottish Physics Syllabus (Sections 1–3).

This 'O' Grade Syllabus will be used by a wide range of pupils, and an attempt has been made to cater for the majority of those concerned. It must however be appreciated that to any one pupil some parts of the book will appear trifling and other parts extremely difficult. Only the teacher can decide which parts are relevant to the needs of a particular class. The Introduction should be regarded as a reference section and not necessarily the first lesson in physics. Again only the teacher can decide when, or even if, reference should be made to it.

Questions are asked throughout the text. The general aim has been to make them of such a nature that pupils will be encouraged to read the whole chapter and perhaps consult other sources in order to answer the questions. Many of the questions are numbered so that they may be used for written homework.

## Techniques

The methods used in this book may be outlined as follows.

(a) *Operational approach to terms.* Here pupils use terms without bothering too much about their definitions. Length is what you measure with a ruler, current is measured in amperes on a meter, temperature is measured with a thermometer. As the course progresses definitions will become more and more evident or will be stated explicitly.

(b) *Concyclic methods will be used.* A subject will be introduced in a casual way, sometimes just the word mentioned and left at that, e.g. temperature in the first few chapters. Later the topic will be raised again and pursued a little further but still left with ragged edges. The next time it appears more progress will be made and so on. No attempt is made to avoid ragged edges. In fact the reverse is true.

(c) *Analogies and models are used throughout.* These can be dangerous if they are considered to be more than illustrations, but I believe that they have a valuable place in any teaching scheme. I would hope that teachers would continually emphasise the limits of such models as, for example, the planetary model of the atom. Some of the analogies (e.g. the water analogy in electricity) will be dropped almost immediately. Others such as the particle model of light may be pursued right on to 'A' Grade.

From all this it is evident that much of what appears in the book is 'wrong' or 'incomplete' or 'misleading'. To say 'You must simplify without falsifying' is unrealistic. Every attempt to simplify falsifies to some extent. Let us accept this and go on to eliminate the falsification progressively. The study of physics has been described as a process of diminishing deception! For example we do not make a point of differentiating between weight and mass at first. Later, we make the distinction, but even then we do not differentiate quantity mass, inertial mass and



gravitational mass, but speak of them as if they are all the same. These distinctions will not be made explicitly at all during the first year's work.

It will be seen that this book is designed to be worked through chapter by chapter. It will not be practicable for the teacher to use Chapter 9 first, then Chapter 12 and follow this with Chapter 3. I am fully aware of the opposition to any prescribed teaching order, but I believe this is one of the sacrifices that must be made if a usable teaching book is to be produced. The Scottish scheme makes this possible for the first time in our history.

## Practical work

No particular class would ever be expected to take part in *every* experiment described here. Again only the teacher can decide which experiments are relevant to the needs of any one class. Many of the experiments can be conducted at home and it is hoped that pupils will be encouraged to carry out some of those as homework projects. On the other hand, several of the experiments described will of necessity be done by demonstration in school. Although the practical work has been grouped under three headings, 'experiments', 'demonstrations' and 'models', these are simply intended to suggest a possible presentation. Many teachers will want individual pupils or groups of pupils to conduct experiments labelled 'demonstration' and no doubt often will find it necessary to demonstrate some of those labelled 'experiment'. In general it is proposed that the 'experiments' will be conducted by pupils themselves, either at home or in school, whenever possible. Some of the 'experiments' and 'demonstrations' may be best conducted as 'group experiments'. In order to avoid confusion between a real experiment and apparatus which has been devised to illustrate a principle the latter will be called a 'model'. It is expected that such models will normally be demonstrated.

## Thanks

This book has been produced with the co-operation and encouragement of so many people that I find it impossible adequately to express my thanks for all the help received. Friends and colleagues from the physics departments of several schools and colleges read the manuscript and made many helpful comments and criticisms.

I am particularly grateful to our lab technician for making and often designing prototype apparatus, to the artist for his amazing patience and skill in interpreting the spirit of the new syllabus and to the publishers for their enthusiasm and guidance throughout the undertaking.

Finally the entire manuscript was read and criticised by Dr Davidson of Aberdeen University. For the time and trouble he so willingly took I should like to express my sincere thanks.

November 1963

J. J.

# How to use this book

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This is not a textbook. It will certainly give you lots of information but it will often demand that you, the reader, find things out or work things out for yourself. The real enjoyment of physics is in the discoveries you make. It is the satisfaction of finding order and even simplicity in things which appear difficult and complicated at first.

It is suggested that you might like to keep a notebook in which you write out the answers to *all* the questions printed in *italics*. If you really want to learn about physics you should answer every question before reading more of the book. It will not really help you if you 'read on to try and find the answer', for very often the answer is not given!

In addition to questions there are various experiments which you should do yourself or see demonstrated. It may not be possible for you to do all of them, but you should attempt as many as you can. The experiments and demonstrations are printed in red. It would perhaps be better to keep a report of your practical work in a separate notebook or alternatively to use a looseleaf book for all your physics work.



# Introduction

The history of physics is the story of man's continual search for satisfactory answers to the questions 'Why?' and 'How?'.

In order to communicate (get the message), we must use words which have the same meaning to both speaker and listener. Practically every question in physics begins with 'Why?' or 'How?'. It is vitally important then that, before we start to study physics, we should know what we mean by these words. They are difficult words, because many people use them wrongly.

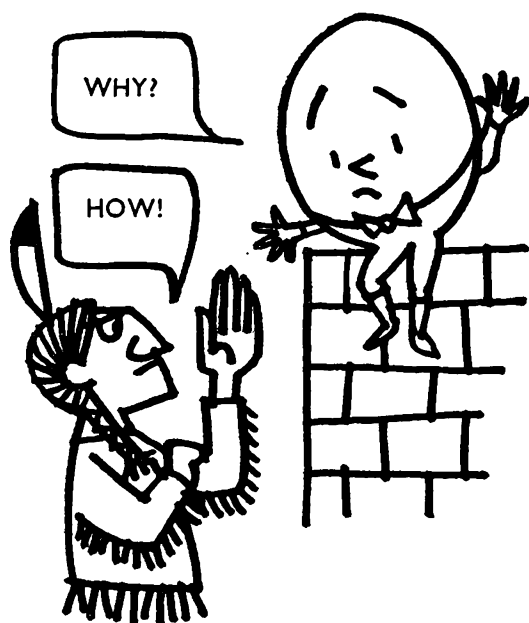


Fig. 1

It is true, as Humpty Dumpty said in *Alice through the Looking Glass*, that words do often mean whatever we want them to mean. Nevertheless, some words must have fairly fixed meanings, especially in science. *Write as many sentences as you can, each showing a different sense in which the word 'iron' is used (1).* The rest of a sentence does not always give a clue to

the meaning of a word. For example—"Why are you going to Paris?" and "How are you going to Paris?" are identical sentences, apart from the first word. In what way do they differ?

## Why?

The 'why' question is much more difficult, for it asks for reasons. Whenever you see a 'why' question, remember the answer should, or at least could, contain 'because'. Reasons are deceptive. Often we give evasive answers to 'why' questions. They are only partial answers. For example, to the question 'Why are you going to Paris?' you might reply 'Because I want to see my aunt'. Is this a complete answer? 'Why do you want to see your aunt?' 'I want to borrow her pen.' 'Why do you want her pen?' . . .

'Why' questions are like this. It is possible to go on and on until you eventually end up with questions verging on philosophy and religion. The second difficulty with 'why' questions is that it is sometimes tempting to think that we have given an explanation when, in fact, we have only given a name.

*Q.* Why is that man not married?

*A.* Because he is a bachelor.

Why is that answer not satisfactory?

*What answer, or answers, would you give to the following question? 'Why do apples fall?' (2) With which famous scientist is this question usually associated? (3).*

## How?

The 'How?' question may be asking through what towns you will pass, that is, 'What is the route?' Or it may be asking whether you are sailing or flying, that is, 'What type of transport?' Hitch-hiking and swimming would not, of

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course, be excluded! 'How' questions may have several meanings, but, by and large, they are fairly straightforward. They ask for a description to be given. Usually 'how' can be replaced by 'in what way'.

In some parts of the country, 'how' is used to mean 'why'. This is very confusing and you would be well advised to avoid this use of the word. The answer to a 'how' question can never start with the word 'because'.

Let us now ask these two questions of physics itself.

### Why do we study physics?

First, then, *why* study physics? The basic answer is that men (and, need I add, women!) are, and always have been, curious. For thousands of years men have wondered why the sun rises and sets regularly, why the stars revolve round one point in the sky, why things fall to the earth, why fires burn, why, why, why. Side by side with his wondering, man has had a sense of wonder or awe. Both qualities are essential for a scientist.

The sciences have expanded so rapidly recently that it is sometimes difficult to know whether a particular subject ought to be studied under one name or another. For example, in the first part of this course, you will be dealing with some aspects of mathematics, astronomy and geology. As they represent the findings of scientists over hundreds, and even thousands, of years, you will have to take many of them on trust. Even here you will, however, be asked to find out some things for yourself. Everything you do ought to help you to answer some 'how' or 'why' question a little more fully.

### How do we study physics?

Secondly, *how* do we study physics? There is no simple recipe. Even accident and inspired guesswork have played their part. Normally, however, the methods of scientists contain the following common features.

#### (1) Observation

Scientists observe carefully what is happening. Notice the distinction between glancing

at something and becoming fully aware of it. During the last 24 hours you may have seen dozens of boats or buses or birds. Could you identify them now? Had you been building scale models of local buses or boats or had you been bird-watching, it might have been a different matter.

If you ever have the misfortune to have to paper a room you will probably find that, for weeks after, you keep seeing flaws in other people's wallpaper. Before this you probably could not have said whether or not they had paper on their walls. 'Seeing ye shall see and shall not perceive.'

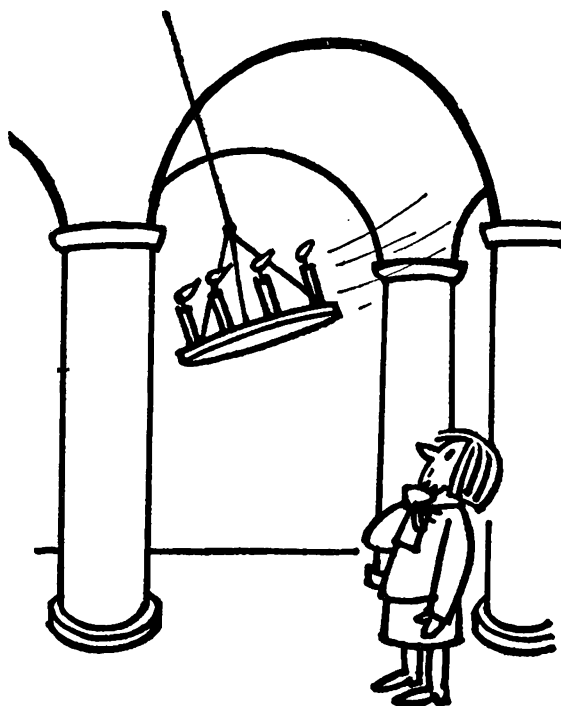


Fig. 2

Lamps have been swinging in cathedrals for centuries but it took a Galileo to discover that the time taken for the lamp to swing to and fro did not change as the swings became smaller. He had no watch. *Can you think of a possible way of timing a swinging lamp if you were given no apparatus whatsoever?* (4)

#### (2) Experiment

This example may be used to illustrate the next stage in the scientific method. Having

noticed the swinging lamp, Galileo designed experiments to study swinging bodies (pendulums). In the laboratory you will be asked to design simple experiments such as this. In an experiment we usually try to alter only *one* quantity at a time and study the effect of this on another quantity. For example, we may study the change in time of swing when we alter the length of pendulum. *Name all the things which you think ought to be kept the same as before (constant) whilst timing pendulums of different lengths.* (5)

### (3) Theory

Step 1, observe. Step 2, experiment. Step 3 is the most difficult of all. Having conducted many experiments and carefully recorded the results, it may take a genius to find a simple pattern into which the results fit. Ought we to expect the results to fit a simple pattern? Look into the back of a TV. set or under the bonnet of a powerful car. Does it look as though modern science aims at simplicity? Nevertheless, it is only because a few simple patterns have been discovered that the highly complicated applications are possible. Our ancestors tried to arrange things in four separate categories—earth, fire, air and water. Today we can consider these things in terms of one pattern, the Atomic Theory, of which more later.

*Example:* Here are some possible results obtained from a pendulum experiment in which only the length is altered. Do not worry at present about the unit in which the length is measured. It is, in fact, slightly less than 1 ft.

| Length of pendulum | Time of swing to and fro |
|--------------------|--------------------------|
| 1 unit             | 1 second                 |
| 4 units            | 2 seconds                |
| 9    "             | 3    "                   |
| 16   "             | 4    "                   |
| 25   "             | 5    "                   |

*Does the time of swing increase or decrease as the pendulum becomes longer?* (6) *Can you find a mathematical connection between the time and the length here?* (7) You will be doing more experiments on pendulums later. This example is given simply to illustrate one way in which a scientist investigates a connection (relation-

ship) between two different things (variables). *Does this experiment answer a 'how' question or a 'why' question?* (8)

### (4) Further experiment

Such a relationship or law is now put to use by a large number of people to see if it always predicts correctly what will happen under new conditions.

We are fortunate in physics because, when we study how two variables alter, it is usually possible to keep all the other variables constant. For example, when we want to see how the time of a swing to and fro (called the period) of a pendulum varies as we vary the length, we can use:

- (a) the same kind of string throughout
- (b) the same bob at the end of the string
- (c) the same size of swing (amplitude)

and, if we conduct our experiment in one place:

- (d) the force of gravity will also be constant.

How many of those did you write down earlier?

In medicine and psychology, scientists find it very difficult to control all the variables. For example, in studying the effects of smoking on lung cancer, it is not possible to investigate a large group of people who breathe the same air, eat the same food and have the same medical record. Nevertheless, by careful and often tedious work, and by using an advanced mathematical technique (statistics), it is possible to produce results which are reasonably convincing.

## Summary

We can summarise the methods by which physics has developed as follows:

(1) *Observation.* Situation is studied while we ask 'why' and 'how'.

(2) *Experiment.* Tests are devised to investigate the situation under controlled conditions. Measurements are taken and recorded.

(3) *Theory.* A theory, hypothesis, law or simple relationship amongst the results is deduced.

(4) *Further Experiment.* More experiments are devised in which the theory is put to use.

## Words, Words, Words

It is a pity that so many words have technical meanings in physics which are different from their use in everyday life. Unfortunately, we cannot alter this situation and the best we can do is to learn the language. Of course, physics is not alone here, for practically every profession and industry has its own technical vocabulary. The difficulty in physics is that so many words mean nearly the same as they do when, for example, a journalist uses them. The physicist's use is not necessarily better or more correct. It is just more convenient to use certain words in a single, strictly defined sense. There are many words like this, for example, heat, work, weight, pressure and power. We will deal with each of these in turn when we come to it.

By studying the ways in which things happen scientists have often suggested simple patterns to describe these happenings. Those patterns, sometimes mathematically expressed, are put forward as hypotheses (inspired guesses often). A hypothesis is tested by many experiments conducted by many people. If all the results are in keeping with the hypothesis it may be written down as a rule or relationship and become known as a law (e.g. Boyle's Law) or a principle (e.g. Archimedes' Principle). It is difficult, if not impossible, to distinguish clearly between those terms. This, at least, they all have in common—they can be used to predict what will happen under certain stated conditions. Here is an example. If a cold body touches a hot body (the stated condition) heat flows from the hot body to the cold body (the predicted result).

## Prediction

The future has always held a fascination for man. For thousands of years, in a variety of ways, he has tried to predict future events. To be able to do this has given him a sense of power which he has sometimes used to control other people. Columbus once had trouble with some Indians who refused to give him food for his crew. Knowing that an eclipse of the moon was due, he threatened to cut off the moon's

light. As soon as the eclipse began, the terrified Indians provided the required food.

Broadly speaking, methods of prediction have followed two distinct paths, which we can illustrate from the study of the heavens—astronomy and astrology. Astronomers have carefully measured and recorded the motions of the celestial bodies over the centuries. By noting certain regularities, and by assuming that these regular patterns of behaviour will be repeated in the future, they have been able to make predictions of amazing accuracy. It was by such studies that Columbus was able to predict an eclipse of the moon and so frighten the Indians.

The history of astrology is very different. It was believed that the lives and fortunes of people on earth were affected by the positions and movements of the stars and the planets. This explains the use of such phrases as 'thank your lucky stars'. The popularity of horoscopes today shows that this belief is not entirely dead. People were often prepared to pay well to be told 'what the stars foretell' and so astrology could be a paying proposition. *Find the origin of the word 'disaster'. (9)*

The methods used in predicting future events might be called superstition and science. They have sometimes both been evident in the work of one man, as in the case of the famous Danish astronomer Tycho Brahe, who also dabbled in astrology.

The applications of science today rely on the dependability of scientific laws. When we press an electric switch we may expect a light to come on, a motor to run, a picture to appear. If the expected result is not obtained we look for a broken switch, a faulty bulb or a shilling to put in the meter. We don't curse science and say that its laws have broken down again!

## Verification and proof

If you have not yet proved that the sum of the angles of a triangle is  $180^\circ$ , ignore this paragraph completely at present.

Science is blamed for having 'proved' an amazing number of things, many of which lie outwith the sphere of science completely. The word 'proof' is, in fact, one which physicists

rarely use. It belongs more happily to mathematics.

Consider Fig. 3.

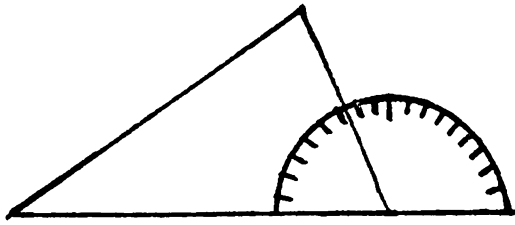


Fig. 3

If we measure the interior angles of a triangle and add them up, we find the sum is  $180^\circ$ . *Does this show that the sum of the angles of other triangles will always be  $180^\circ$ ?* (10), i.e., Does this *prove* the statement 'The sum of the interior angles of a triangle equals  $180^\circ$ '? In fact, the more triangles we measure the more likely it is that the statement is correct, but we can never be quite sure that perhaps the next triangle we measure will be different. By using one triangle we are showing that the statement is true for this particular triangle. We are, in fact, *verifying* the statement. In physics we use this term when we test out a law or a theory to

see if it helps in particular cases. Physics experiments, then, deal with verifications rather than proofs.

### Geometrical proof

If we accept certain axioms about alternate angles and corresponding angles between

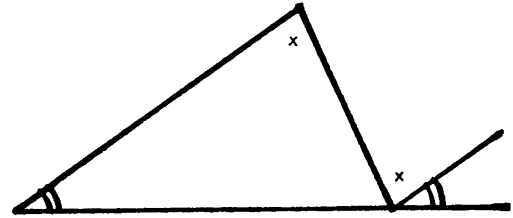


Fig. 4

parallel lines, it is a simple matter to *prove* that, in any triangle, the sum of the interior angles is  $180^\circ$  (Fig. 4). The above construction can be applied to every triangle and the same reasoning will hold. It is less confusing if we retain the word 'proof' for this type of work.

As physics deals with the way things behave in the physical world, it is better to avoid terms such as 'right', 'true' and 'proved' which suggest that the last word has been said on the subject.



# Measurement

## CHAPTER 1

### Accuracy

Lord Kelvin once said that unless you can measure what you are speaking about and express it in numbers you have not advanced to the stage of science. Physics is an exact science. It deals with accurate measurements but the degree of accuracy at which you aim should depend entirely on the purpose for which you are making the measurements. There is no such thing as absolute accuracy. You will never be absolutely correct when you take physical measurements. This does not mean that accuracy is unimportant. What it does mean is that you should think about the measurements you are taking and decide approximately what degree of accuracy you require and can expect. Estimating accuracy of measurements is really rather difficult, but there are one or two simple mistakes you can avoid now.

Imagine that you were measuring the over-all length of a toy car, say a model Jaguar. You could not lay a ruler from bumper to bumper, so that any reading taken with a ruler alone would be a rough estimate. If the length were found to be roughly 2 in and you were only concerned to see if the car would fit into a toy garage which was  $2\frac{1}{2}$  in long, this degree of accuracy would be sufficient. Any further

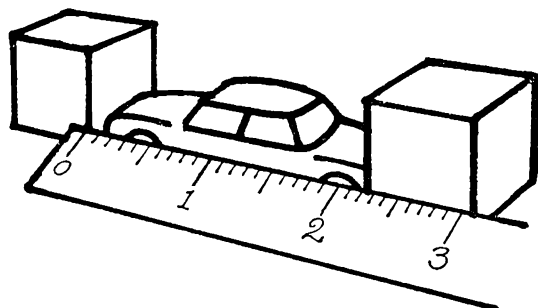


Fig. 5

measurement would be a waste of time. If, however, you intended to make a small box in which to pack it, you would require a more accurate measurement of length.

This could be obtained by measuring the car, using two wooden cubes as shown in Fig. 5. *Can you suggest any ways in which even this method gives inaccurate results? (1)*

Whenever you are designing an experiment or taking measurements you should be thinking about what degree of accuracy is required.

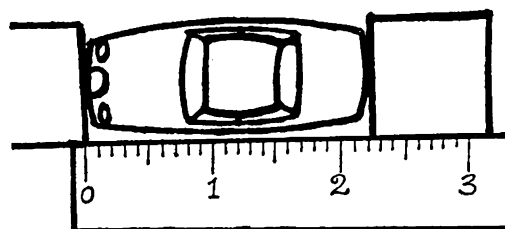


Fig. 6

Imagine that the reading on the ruler was as shown in Fig. 6. *What is the length of the car? (2) Is it 2 in, 2.2 in, 2.22 in, 2.222 in, 2.23 in, 2.3 in?* Consider the following example. If we bought 13 yd of electric cable, we would not be terribly worried if we found on measuring it that it was only 12 yd  $35\frac{1}{8}$  in. We would, however, feel that we had been cheated if there was only  $12\frac{1}{2}$  yd and we would patronise the firm more often if we found  $13\frac{1}{2}$  yd!

Strictly speaking, to the physicist the measurement 13 yd represents any length between 12.5 and 13.5 yd. How, then, can he express exactly 13 yd? As absolute accuracy does not exist, the measurement 'exactly 13 yd' does not exist either.

|                 |               |            |
|-----------------|---------------|------------|
| 13.0 yd means   | 12.95 yd to   | 13.05 yd   |
| 13.00 yd means  | 12.995 yd to  | 13.005 yd  |
| 13.000 yd means | 12.9995 yd to | 13.0005 yd |

and so on. Theoretically, it would be possible to express 'exactly 13 yd' by 13 followed by a decimal point and an infinite number of zeros.

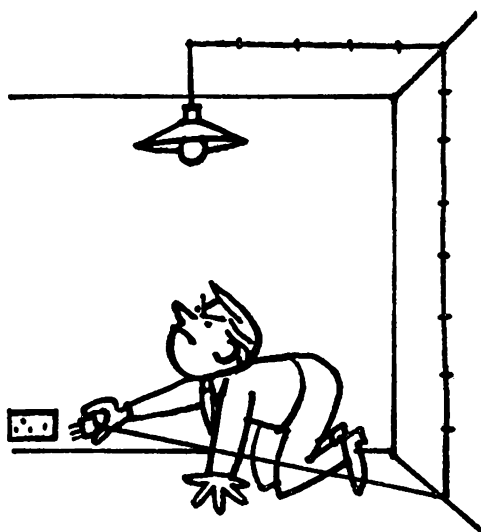


Fig. 7

Now let us return to the length of the model car. The reading on the ruler is between 2.20 and 2.30. The best estimate here is probably 2.22. *What can you say about the last figure in the reading 2.222?* (3) *If this were a correct reading, between what limits must the length of the car lie?* (4)

**Experiment 1.1.** Take a small car, for example a Dinky toy, and measure its length. Now find out the length of the car which the toy represents and then calculate the number of times the car is longer than the model. This enables us to find the scale of the model. 1:100 or  $\frac{1}{100}$  means that 1 in of model represents 100 in of real car, or the model is one-hundredth of the size of the real thing.

### Estimation

One of the greatest enemies of accuracy is unthinking arithmetic, that is, a blind manipulation of numbers without thinking about the answer expected. Wherever possible you should cultivate the habit of estimating a quantity first, even if you are going to make accurate measurements later. Silly mistakes in arithmetic can often be avoided in this way. If you

are measuring the area of a wall and estimate it at say 10 ft  $\times$  10 ft, you are not likely to end up with a calculated answer of 1,066 sq ft.

### Averages

In practice scientists usually take far more than one reading when they are measuring. Here are results obtained from ten pupils who were asked to measure the length of a bench with a metre stick.

|          |           |
|----------|-----------|
| 425 cm   | 425.13 cm |
| 424 cm   | 423 cm    |
| 424.5 cm | 324.1 cm  |
| 426.1 cm | 424.2 cm  |
| 420 cm   | 423.16 cm |

Study these results and answer the following questions.

*Which of these results would you reject?* (5)  
*Why?* (6)

*Which of these results do you think have been stated too accurately?* (7)

*Rewrite these 'over-accurate' results in the way you think they ought to have been stated.* (8)

*Which of these results have not been given with sufficient accuracy?* (9)

*Find what, in your opinion, is the best estimate of the length of the bench.* (10)

**Experiment 1.2.** Try an experiment of this kind in the lab and record all the results obtained. Calculate the average value *after* rejecting the unsatisfactory results.

### Approximation

Accuracy and approximation are two sides of the same coin. In trying to arrive at a picture of the heavens we will be continually using approximations. Knowing when and to what extent to approximate is a very difficult but important part of physics. It is worth while spending some time thinking about approximations. Consider this problem. If the sun were represented by a football, would the moon be represented on the same scale by:

- (a) a similar football?
- (b) a tennis ball?
- (c) a table tennis ball?

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- (d) a marble?
- (e) a pea?
- (f) a grain of barley?
- (g) a pin head?

It is more important, at present, that you should have some idea which of the above possibilities are more nearly correct than that you should swot up a list of numbers indicating the diameters of the sun, the moon and the planets. It is, however, very important that astronomers should know the measurements of the solar system with great accuracy.

Here is an example of accuracy in astronomy. How long does the Earth take to circle the sun? In other words, how many days are there in a year? This is really a very difficult question, for we have to know very clearly what we mean by 'day' and 'year'. You would probably answer the question by saying 365 or  $365\frac{1}{4}$ , but hundreds of years of careful study have led astronomers to believe that it is 365.242195. They are not too sure about the last 5! *Apart from astronomers, to whom do you think this kind of accurate information is very important? (11)*

### Astronomical numbers

#### (1) Light years

Whenever we measure very large or very small distances, masses or times, we find that the writing of our results becomes clumsy. Apart from our own sun, the star nearest to the Earth is so far away that light from it takes 4 years to reach us. *If light travels at 186,000 miles every second, find out how far away the star is. (12)* This is a very clumsy number and so a shorthand method of expressing it is used. The star is said to be 4 light years away. This simply means that light, travelling at 186,000 miles per second, takes 4 years to travel this distance.

#### (2) Powers of ten

Another shorthand way of writing down very large numbers is to count up all the zeros and state the number of zeros as a 'power of 10'. You will deal with this more fully in mathematics later on. Regard this, at present, simply as a shorthand way of writing down multiplication by 10, e.g.

|                                                                                       |                                |
|---------------------------------------------------------------------------------------|--------------------------------|
| $70 = 7 \times 10$                                                                    | $= 7 \times 10^1$<br>(1 zero)  |
| $700 = 7 \times 10 \times 10$                                                         | $= 7 \times 10^2$<br>(2 zeros) |
| $7,000 = 7 \times 10 \times 10 \times 10$                                             | $= 7 \times 10^3$<br>(3 zeros) |
| $7,000,000 = 7 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10$ | $= 7 \times 10^6$<br>(6 zeros) |

Of course, you cannot express a number like 7,123,456 this way unless you write  $7.123456 \times 1,000,000 = 7.123456 \times 10^6$  which is not really an advantage! This quantity could, however, have been stated approximately as  $7 \times 10^6$  or  $7.1 \times 10^6$  or  $7.12 \times 10^6$ , depending on the accuracy required.

The mass of the Earth is about  
5,980,000,000,000,000,000,000,000 g,  
which is much more simply written as:

$$\begin{aligned} 598 \times 10^{25} \text{ g or} \\ 59.8 \times 10^{26} \text{ g or} \\ 5.98 \times 10^{27} \text{ g.} \end{aligned}$$

It is the usual practice to have only one digit before the point when expressing quantities in this way, although this is not essential. In the example quoted above the figures 5, 9 and 8 are called significant figures. The mass is said to have been given 'to 3 significant figures'. We could round off or approximate to two significant figures. *Is 598 better expressed approximately as 590 or 600? (13)*

If the last digit of a number is less than 5 take it as zero when approximating. If 5 or more, take it as 10, e.g.

$$\begin{aligned} 356 \text{ becomes } 360 \\ 351 \text{ becomes } 350 \\ 355 \text{ becomes } 360 \end{aligned}$$

The mass of the Earth is, therefore,  $60 \times 10^{26}$  g or  $6.0 \times 10^{27}$  g expressed to two significant figures.

*To how many significant figures are we expressing the mass of the Earth if we write  $6 \times 10^{27}$  g? (14)* Note that 6.0 g means 5.95 g to 6.05 g and that 6 g means 5.5 g to 6.5 g.

*Express the following numbers in this shorthand form, putting 1 digit before the point and then multiplying by a power of 10 (15),*

e.g.  $638,000 = 6.38 \times 100,000 = 6.38 \times 10^5$

700.0 =

280.00 =

4,960 =

8,247,000 =

15,060 =

92,520 =

1,600,000 =

186,000 =

Now express all the above quantities to 3 and then to 2 and, finally, to 1 significant figure. (16)

The above shorthand method may, of course, be used for any quantity, including length. If we take one centimetre as our unit of length then:

$10^1$  cm represents 10 cm—about the diameter of a cricket ball  
 $10^2$  cm „ 100 cm—about the height of a bicycle

|              |   |                                                            |
|--------------|---|------------------------------------------------------------|
| $10^3$ cm    | „ | 1,000 cm—about the height of a two-storey house            |
| $10^4$ cm    | „ | 10,000 cm—about the height of a skyscraper                 |
| $10^6$ cm    | „ | 1,000,000 cm—about the height of Mount Everest             |
| $10^9$ cm    | „ | about the diameter of the Earth                            |
| $10^{11}$ cm | „ | about the diameter of the sun                              |
| $10^{13}$ cm | „ | about the distance from the Earth to the sun               |
| $10^{19}$ cm | „ | about the distance to the nearest star                     |
| $10^{28}$ cm | „ | about the distance to the farthest galaxy ever seen by man |

### (3) Models and scale drawings

Diagrams, photographs and models are often scale representations.

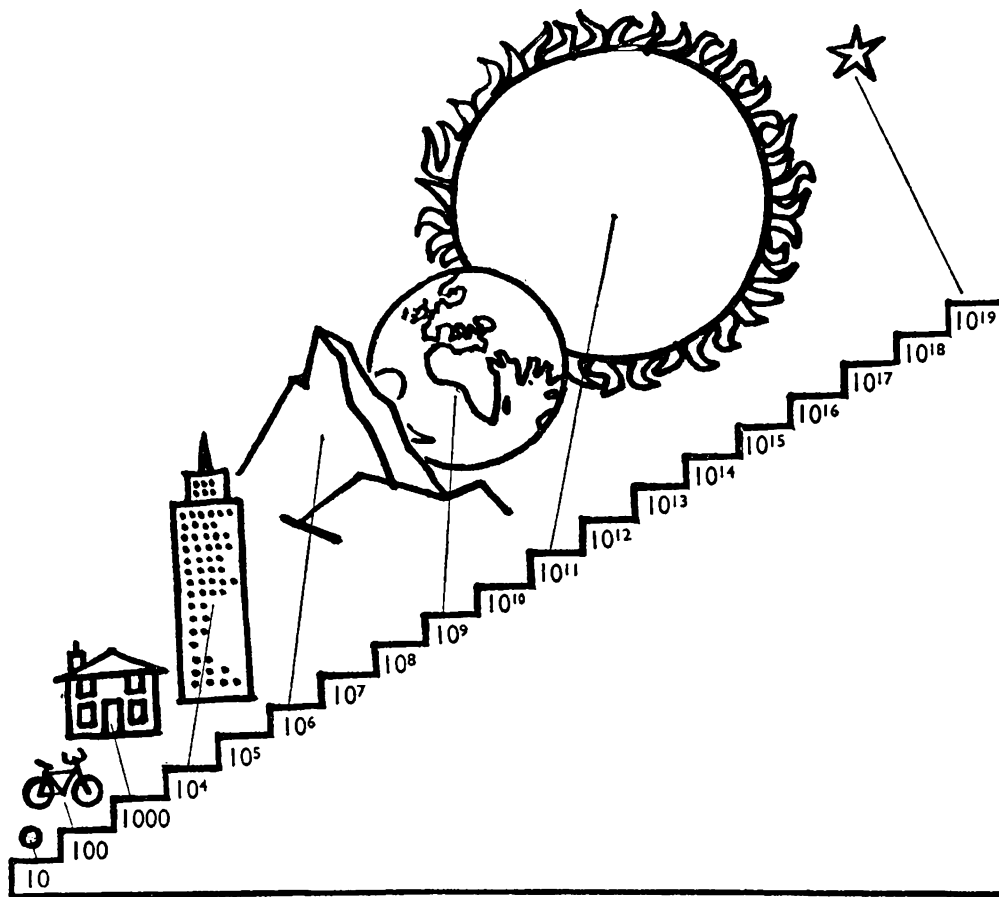


Fig. 8

(a) They may represent a large object on a small scale, as in the case of a photograph of a mountain or a diagram of a Morris 1100.

(b) They may be exactly the same size as the object they are meant to represent, as may be the case with a toy mouse or a drawing of a frog.

(c) The representation may be many times bigger than the object it represents, as is so with models of atoms or molecules and diagrams of crystals or bees' legs.

Difficulties arise when we use different scales in the one diagram. A photograph is not usually a good scale representation. *Why?* (17)

*Can you think of any particular type of photograph which could be a good scale representation?* (18) *How would you check this?* (19)

A map is a good example of the first type of scale drawing. Some maps sold by the petrol companies have a scale of 5 miles to the inch.

*What would be the distance on such a map between the centres of Edinburgh and Glasgow?* (20) The actual distance as the crow flies is about 42 miles.

*Using the map shown in Fig. 9 and the scale given find the approximate distance between Edinburgh and Kirkcaldy via the Kincardine Bridge. (21) How far is it via the Forth Road Bridge? (22)*

*What would be the length of a 220-ft castle drawn to scale on a 5-miles-to-the-inch map? (23) Give your answer as a decimal fraction of an inch.*

It is obviously impossible to represent such a building on the map on the same scale as the map itself. The castle could, however, be drawn on a scale bigger than the scale of the map. *Can you suggest a suitable scale?* (24)

*Study a road map and find out if the thickness of the lines used to represent the roads is on the same scale as the map itself. (25)*

We will be forced, sometimes, to represent

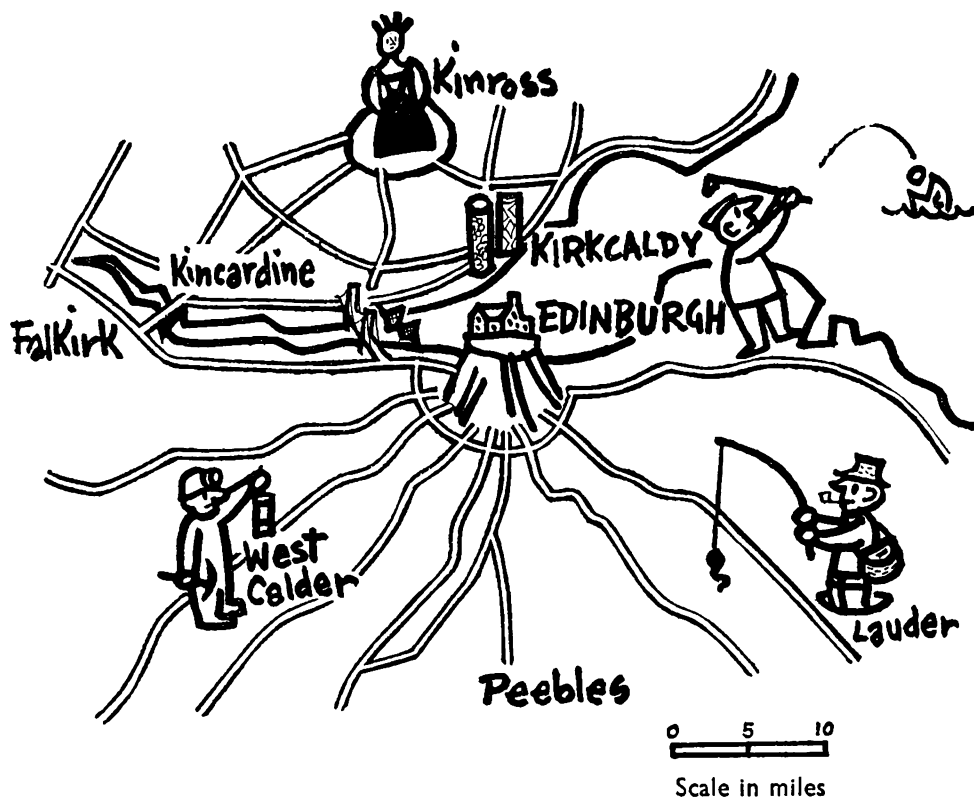


Fig. 9

objects by different scales on one diagram. This is particularly true when dealing with tiny things like atoms or molecules and enormous systems such as the sun and the planets. Whenever you look at a diagram ask yourself if all the lengths represented on it are drawn to the same scale.

## Summary

To enable us to discuss the enormous distances involved in space we shall use three devices:

- (1) light years (l.y.)
- (2) powers of 10 (index notation)
- (3) models and scale drawings.

# Our place in the universe

## CHAPTER 2

### The universe

'In the beginning, God created the heaven and the earth.' Today, thousands of years after those words were first written, man still does not know when or how the Earth was created. Scientists still argue about its past and its future.

Before reading further, spend some time studying the sky on a clear, dark night. Can you recognise any of the groups of stars (constellations)? *How can you identify the Pole Star? (1)*

On a clear night it is possible to see nearly 3,000 stars with the naked eye. Until 350 years ago all astronomical observations were made in this way and yet some quite amazing discoveries were made. For thousands of years man has studied the heavens and developed about as many theories as the stars he observed. If we were to follow through the history of astronomy we would have no time for anything else and so we must compress the work of thousands of years into fewer minutes.

**Experiment 2.1.** If you have a camera, or can borrow one, try this simple experiment. Choose a clear night with no moon and fix your camera so that it is pointing at the Pole Star. Open the aperture as wide as possible (i.e. the smallest 'f' number), and, with the shutter set to 'time exposure', leave it open for several hours. What does the photograph you obtain tell you?

Why has man taken such a keen interest in astronomy? Three of the main reasons are practical ones—his need for a compass, a calendar and a clock.

We know that the Egyptians, Greeks and Chinese all studied the heavens and gave names to the constellations. About 5,000 years ago the Egyptians were using their knowledge of the

movements of stars to navigate their boats in the Mediterranean.

It must have been a laborious job to watch the stars and note down exactly where they

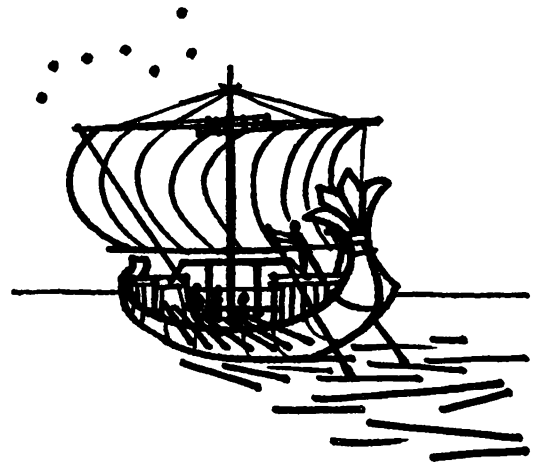


Fig. 10

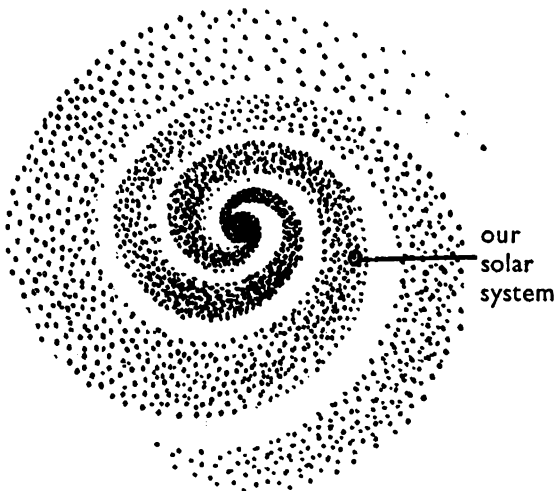
were seen on different nights. In Egypt, men called 'hour-watchers' sat patiently observing the stars from the roofs of their temples. Their observations were recorded and it was found that the stars circled the Pole Star approximately once every day. But they also knew that it was not *quite* once per day and that, as the year progressed, different sets of stars became visible. Man soon learned that certain constellations appeared at the same time each year and thus he learned to plant his grain when a particular constellation or star was first seen in the sky. The astrologer-priests gave names to the twelve special constellations—one for each month of the year. They are called the signs of the zodiac. The brightest star in the night sky is Sirius. The Egyptian new year began with its return to the sky in August. It also warned those who lived in the Nile Valley

that floods were coming. We thus see that from his study of the stars man first learned to navigate and to tell the seasons.

At this time man thought of the Earth as being flat and lying at the very centre of the universe. The stars were tiny lights fixed in an inverted celestial pudding bowl.

## The galaxy

It is now known that the nearest star, apart from one, is 25 million million miles away, i.e. 4 light years. *What is the one exception?* (2) *Why could you not live on a star?* (3) Some stars are hundreds and some millions of light years away. If you could visit the Constellation of Orion and could be at present on the star Rigel and could view the Earth with a 'super telescope', you could watch Columbus crossing the Atlantic.



The Milky Way

Fig. 11

Put more realistically, light from Rigel reaching the Earth today was radiated from the star about the time of Columbus.

The stars of the universe are grouped together in vast collections or galaxies. In our galaxy, called the Milky Way, there are some hundred thousand million stars. Travelling at 186,000 miles per second, light takes 100,000 years to travel across the Milky Way from edge to edge.

The Milky Way is, however, only one galaxy.

There are probably thousands of millions of such galaxies in the universe. The nearest galaxy to our own is the Great Galaxy of Andromeda. It is comparable in size to the Milky Way and is nearly 2 million light years away.

'What is man that Thou art mindful of him?'

## Radio astronomy

The Jodrell Bank radio telescope is familiar to everyone today, yet radio astronomy began only 30 years ago.

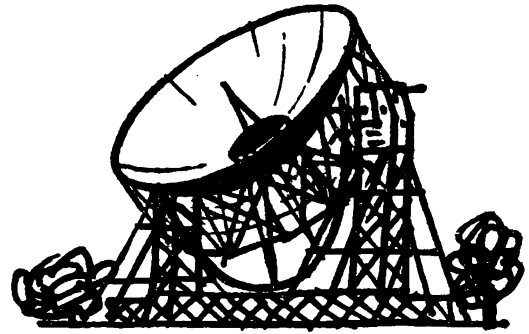


Fig. 12

About that time a young American engineer, Karl Jansky, was working for the Bell Telephone Laboratories. Jansky was unfortunately not very strong and his doctor ordered him to live quietly. He was therefore sent to a small experimental station in the country where he was asked to investigate the hisses and crackles sometimes heard in a radio set—'atmospherics'. He built a huge aerial which could be rotated like a merry-go-round. With this aerial he discovered that some of the hiss appeared to come from outer space. Moreover, the source of this hiss seemed to be moving. He was not an astronomer but he read every available book on the subject. Finally, Jansky was able to demonstrate that the hiss which he was hearing in the loudspeaker of his radio set was coming from the Milky Way. Today very large aerial arrays or huge reflectors, such as the 750-ton dish at Jodrell Bank, are used to detect the tiny radio signals coming to us from outer space. The radio telescope is helping us to learn more and more about the amazing universe in which we live.



## The sun and the planets

We have not yet mentioned the one star which is the most important to us; the one which provides practically all our light and heat; the one which for centuries was worshipped as a god and in whose honour temples were built throughout the world.



Fig. 13

The great stone ruins at Stonehenge are thought to date back to around 2000 B.C. and to have some connection with sun worship in this country. Presumably the sun was seen more frequently in those days!

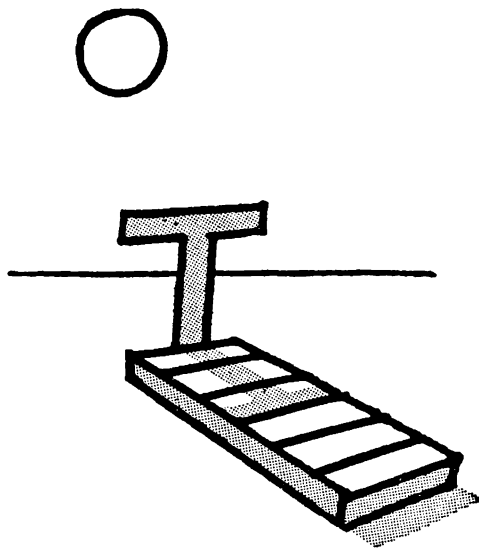


Fig. 14

The first sundials were probably built in Egypt about 1500 B.C. The crossbar cast a shadow on a marked strip of wood, thus indicating the time.

About 350 years ago a Dutch spectacle maker called Lippershey arranged two spectacle lenses

in such a way that he was able to see distant objects more clearly than with the unaided eye.

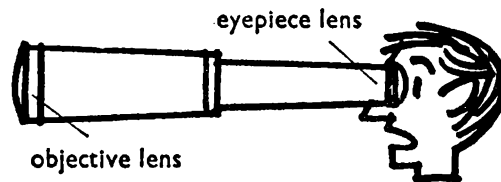


Fig. 15

**Experiment 2.2.** Try to make a simple telescope. You will require two lenses; one fairly flat and one fairly fat. Old spectacle lenses can be quite suitable. You should test them first to make sure that they are both magnifying glasses as some spectacle lenses (concave) have a shrinking effect. Suitable lenses would have focal lengths of about 50 cm (+2 dioptres) and 10 cm (+10 dioptres). Use the flat lens as the objective, that is the lens nearer the object. Use the other as the eyepiece lens. You also require some glue and two cardboard tubes of such a size that one will slide inside the other. The lenses can be secured by rings of cardboard glued inside the tubes or by Plasticine. (Sets of 36 assorted spectacle lenses are available cheaply from Philip Harris. Two suitable lenses for a simple telescope may be bought from Charles Frank for 5s. 6d. The addresses of these and other suppliers may be found at the end of the book.)

The over-all length of the telescope will be about 2 ft for the lenses stated, but this depends on your lenses. Try the lenses out together first to determine how long the tubes should be.

An alternative but less exciting way to study the heavens is to use binoculars. They may be marked thus: 7×50. This means that they magnify 7 times and have objective lenses 50 mm in diameter. For astronomical work the bigger those quantities are the better.

You are now ready to do some more star gazing. Using your telescope or binoculars examine the Milky Way. *Of what is it made up?* (4) *Can you discover any other bodies in the sky apart from stars?* (5) *In what way do they differ from the stars?* (6) Consult a newspaper, for example *The Scotsman*, which prints diagrams

of the sky and also gives information as to what to look for each month. Reprints from *The Scotsman* are available from the Robert Cormack Bequest, George Street, Edinburgh. One word of warning here; *never* look at the sun directly or through a telescope or binoculars. If you want to view it, use a smoked glass or thick black photographic negative such as might result from leaving your camera lens open in sunlight.

*Can you now say something about the different ways in which the sun, the moon and the planets move across the heavens? (7) What is the origin of the word 'planet'? (8)*

The history of man's interpretation of the heavens is bound up with astrology, superstition, philosophy and religion. About 500 B.C. Anaxagoras, a Greek philosopher, said that the sun was not a god. It was merely a glowing metal sphere. The moon, he claimed, reflected the light from the sun. As this was contrary to the Greek religion he was arrested.

Two hundred years later Aristarchus asserted that the Earth was not the centre of the universe. He said that the Earth and the planets circled round the sun. Other great thinkers, such as Aristotle and Ptolemy, preferred the Earth-centred theory. As the Greeks left their servants to do the menial jobs, which included doing experiments, the philosophers placed less importance on observations than we do today. They preferred to rely on logic and argument. It was fashionable to follow the teachings of the philosophers, and so the Earth-centred theory was accepted and the other forgotten for centuries.

Just over 400 years ago the Polish astronomer Copernicus published a book in which he described 'The Revolutions of the Heavenly Spheres'. In it he suggested that predictions could be made more easily by considering that the Earth and the planets revolve round the sun. Fifty years later an Italian scientist, Galileo, developed the telescope invented by Lippershey and used it to study the heavens.

With his telescope Galileo was able to see, for the first time, that one of the planets, Venus, appeared like the moon, sometimes full, sometimes crescent. He thought that one of the planets, Jupiter, had moons of its own. He saw

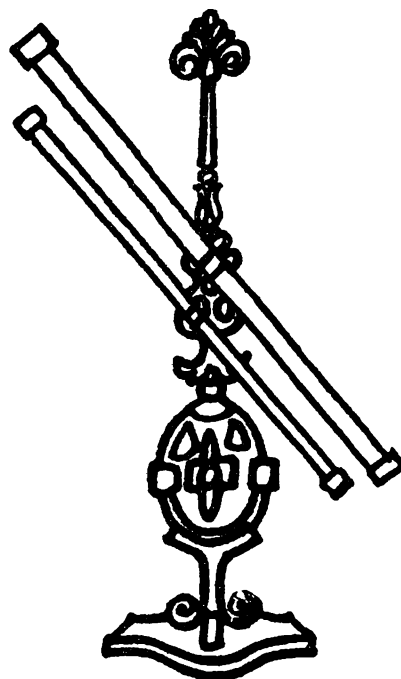


Fig. 16

the great mountains and craters of the moon. He became more and more convinced that Copernicus was correct—the sun was the centre of the solar system. He wrote a book in which he discussed 'the two great systems of the World—The Ptolemaic and the Copernican'. The book was called *The Dialogue* and it made it perfectly clear that he thought that the Earth-centred system taught by Ptolemy was nonsense. For this he was brought before the Inquisition at Rome, when he was nearly 70 years old, and under threat of torture was forced to deny his belief in the Copernican system. Tradition has it that he was so convinced that it was the Earth that moved that the moment he was released Galileo stamped his foot and said 'E pur si muove', that is 'and yet it moves!' Perhaps much of the trouble caused could have been avoided if Galileo had been content to regard the Copernican system as a theory, a hypothesis or, what is the same thing, a useful picture. Galileo went further and claimed that it was 'true'. This is a dangerous description of any scientific theory.

Some years later Giordano Bruno suggested that space was infinite and contained stars which

were similar to our sun. For this he was burned at the stake as a heretic.

Two other names ought to be mentioned here—Tycho Brahe and one of his pupils, Johannes Kepler. Brahe devised and built many instruments to measure the positions of the stars. Kepler worked out the mathematics of planetary motion. Until then, astronomers had assumed that the planets must move in circles, as a circle was the perfect figure. Kepler showed that the planets move in ellipses round the sun.

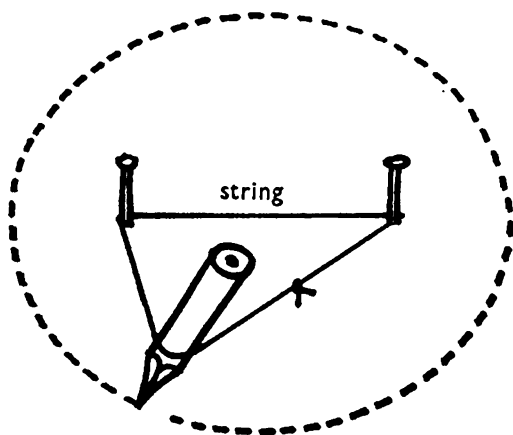


Fig. 17

**Experiment 2.3.** Try to draw an ellipse in the following way. Place a loop of string loosely over two drawing pins pushed into a piece of wood. Now take a pencil so that it is just held by the string and trace out the figure.

*What happens to the figure as the two pins are brought closer together? (9) When would the ellipse become a circle? (10)*

The planets move in ellipses, but they are, in fact, very nearly circles. Some comets, on the other hand, move around the sun with elliptical orbits which are very far from circles. The point on the ellipse farthest from the sun is called the APHELION. *What is the nearest point called? (11) Do artificial earth satellites move round the Earth in circles or ellipses? (12) What do you call the points on their orbits nearest to and farthest from the Earth? (13)*

*Find out what you can about the orbits of the latest satellites which have been sent up. (14)*



Fig. 18

## Gravity

**Experiment 2.4.** Take a cork securely tied to a piece of string and whirl it round your head. Now let go. What happens to the cork? Why do the whirling planets not do the same?

It remained for Sir Isaac Newton to provide the answer to the last question. He said that all bodies, great or small, attract each other to some extent. We will discuss his 'Theory of Gravitation' later, but for the moment assume that the greater the mass of the body the greater the pull it has on another body. The sun, therefore, must exert a tremendous pull on the planets. They are 'tied' to the sun by 'invisible strings'. *What is this force called? (15)* It is the same type of force which is responsible for things falling to the ground when they are dropped, but it took the genius of Newton to see that the fall of an apple and the orbit of the moon were related. In order to overcome gravitational attraction and leave the Earth a rocket has to be fired at the enormous speed of 25,000 miles per hour. The moon is very much smaller and lighter (has less mass) than the Earth, so that the gravitational attraction on the moon is much less than on Earth. It has, in fact, only one-sixth of the Earth's pull. *Would this affect the speed which a rocket would have to reach in order to leave the moon? (16)*

## Visual aids

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The following filmstrips contain excellent illustrations for Chapters 2 and 3:

*The World We Live In*, Part I. 'The Earth is Born', from Life Filmstrips.

*Astronomy (360)*, from the Hulton Press.

*Measuring the Earth*, Part I. 'Time and Distance', from Educational Productions.

An excellent wall chart showing the sky at night is available from the *Daily Telegraph*.

# The solar system

## CHAPTER 3

### Measuring large distances

About 550 B.C. Pythagoras (the 'square' on the hypotenuse) taught that the Earth was a sphere. Ancient mariners noticed that as they sailed north the Pole Star appeared higher in the sky. When ships went out of sight 'over' the horizon

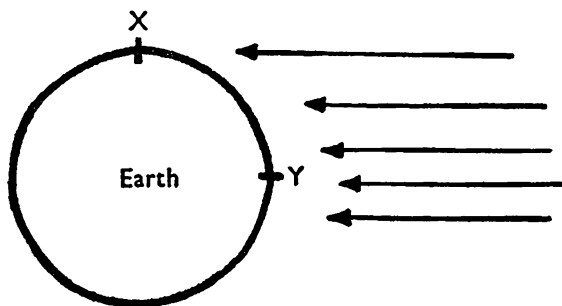


Fig. 19

they saw the hull disappear first and the top of the masts last. When the moon was eclipsed, the Earth's shadow on the moon was seen to be circular. Those observations can be explained if the Earth is a sphere, but not if it is flat. In spite of this, few people agreed with Pythagoras.

*Can you mention some recent evidence which*

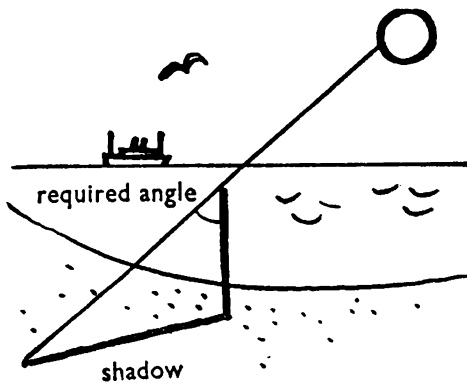


Fig. 20

*also confirms the belief that the Earth is spherical? (1)*

About 300 B.C. Eratosthenes worked out the circumference of the Earth in this ingenious way.

A man standing at Y (Fig. 19) finds that the sun is overhead. At the same time another observer at X sees the sun on the horizon. As  $90^\circ$  is  $\frac{90}{360} = \frac{1}{4}$  of a complete circle the distance from X to Y must be  $\frac{1}{4}$  of the Earth's circumference. If this can be measured then the total circumference can be found. The angle at which the sun's rays strike the Earth could be found by measuring the shadow of a vertical pole. *How long would the shadow be at X and at Y? (2)*

**Experiment 3.1.** Use a vertical pole (a metre stick will do) to find the angle the sun makes with the vertical at noon.

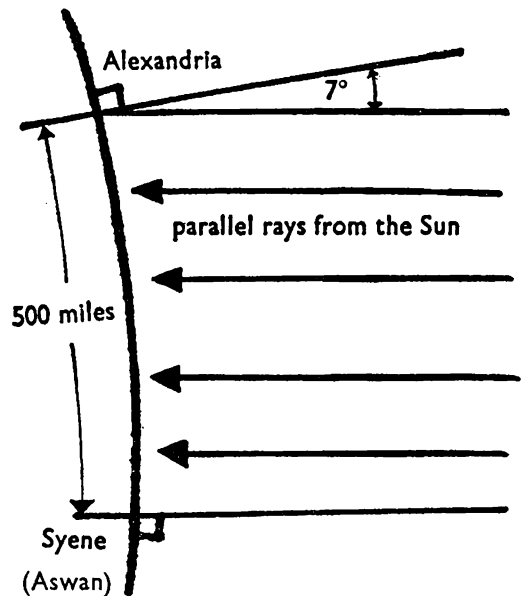


Fig. 21

*How can you be sure that the pole is vertical? (3) How can you check that a surface is horizontal? (4) What is the angle between a vertical and a horizontal line? (5)*

Eratosthenes used a very much smaller part of the Earth's circumference. He found that at Syene at noon on a certain day the sun was immediately overhead (Fig. 21). At exactly the same time (noon) another observer 500 miles due north at Alexandria found the sun making an angle of  $7^\circ$  with the vertical. 500 miles must be  $\frac{7}{360}$  of the Earth's circumference. *Calculate the total circumference of the Earth from those figures. (6)*

Later you may like to try this experiment by working with pupils from another school several hundred miles due north or south of your own. Reasonable results have been obtained by pupils in Edinburgh and Exeter taking observations at the same time.

#### More scale drawings

If you wanted to find the width of a river from one bank you could use the following method.

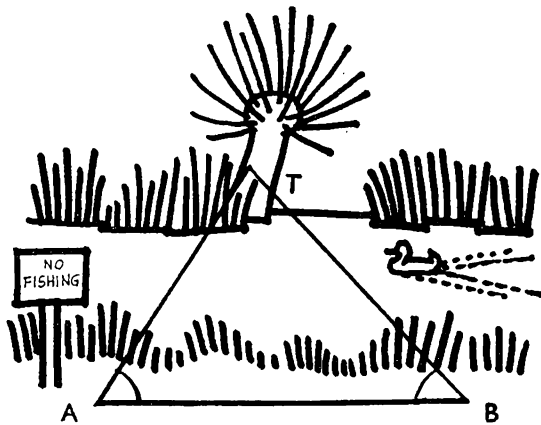


Fig. 22

**Experiment 3.2.** Ask one boy to stand at A and another at B (Fig. 22). Measure the distance between them. Ask the boy at A to find the angle  $TAB$  by sighting first on a tree on the opposite bank and then on the boy at B. The other boy should find the angle  $TBA$  in a similar way. A scale drawing should then be constructed and the width of the river found.

Using a blackboard protractor try out the above method in the playground. Then check your results by direct measurement.

A method similar to this can be used to find how far the moon is from the Earth.

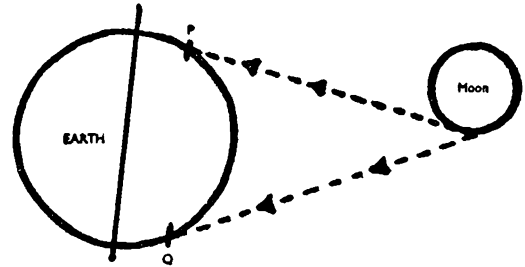


Fig. 23

If observations were made from two distant points, P and Q (Fig. 23), on the Earth's circumference a scale drawing could be constructed to find the distance of the moon from the Earth. The length of the base line PQ must of course be known. In practice rather more involved techniques are used to measure the distance from the Earth to the sun and to the moon.

#### How big is the moon?

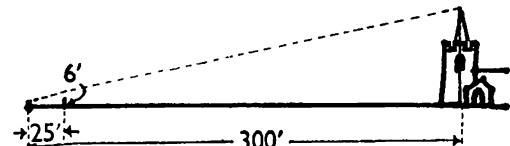


Fig. 24

A scout would use his staff to estimate the height of a steeple. *If the steeple were 300 ft from the scout (Fig. 24) how high would it be? (7)*

**Experiment 3.3.** Devise an experiment using this method to find the diameter of the moon. Assume that it is 240,000 miles away.

#### How far away are the stars?

When we try to find out how far the stars are from the Earth the diameter of the Earth is too small to form a base line. Sightings are

made on a star at six-monthly intervals so that the base line now is  $2 \times 93$  million miles.

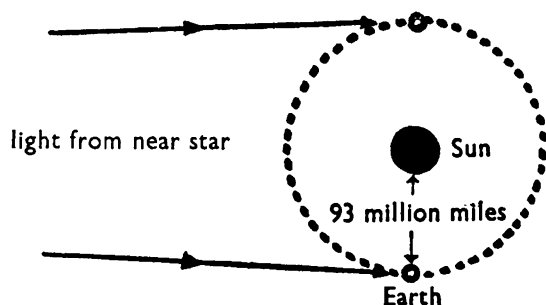


Fig. 25

## The planets

The sun is far bigger than any of the planets. Its diameter is about 864,000 miles and it contains nearly 99.9 per cent of the total mass of the solar system. The temperature inside the sun has been estimated at 36 million degrees Centigrade. In producing heat by thermonuclear reactions the sun loses about 4 million tons of its mass every second! But even so the sun is 'small fry' compared with many other stars.

Around the sun spin many planets. For centuries there were thought to be seven, for seven was regarded as the perfect number. There were seven days, seven metals, seven planets. The planets were named after the gods.

Mercury: The messenger of the gods. It moved rapidly across the sky.

Venus: Goddess of love. The brightest planet.

Mars: God of war. It appeared red—the colour of blood.

Jupiter: The king of the gods. The largest of the planets.

Saturn: God of time. It moved slowly.

The other two planets were the Earth and the moon.

### 'In the beginning . . .'

The study of the continuous breakdown of radio-active elements in nature has enabled scientists to obtain an estimate for the age of the Earth. It seems probable that these elements cannot be older than 5,000 million years. It may

be, then, that all the elements in the Earth and the planets have been created within this period.

The first plant life seems to have appeared about 600 million years ago while man's history is less than one million years old.

Some of the stars which were at first thought to be single stars are now known to be twins (Fig. 26). Mizar, one of the stars in the Plough, is of this kind. Such a star is called a binary. Sometimes one of the stars explodes, and astronomers tell us that in some cases this is taking place at present. The Crab nebula is the result of such an explosion. It took place

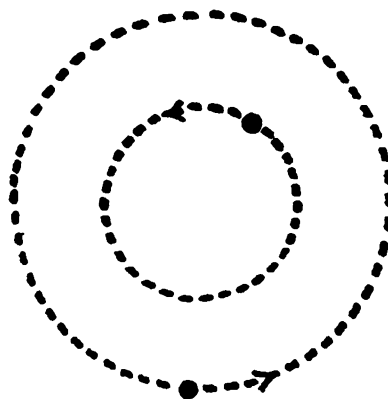


Fig. 26

over 900 years ago, since when the pieces have been travelling outwards from the explosion. One of the many theories which have been put forward to account for the formation of the system of planets suggests that our sun may have been part of a two-star system. If our sun's partner exploded most of the particles would be thrown into space. Because of the pull of the sun some gas particles would however remain close to the sun and would encircle it rather like the rings of Saturn. The gas particles may then have gradually come together to form great globes. Perhaps the globes themselves ultimately broke up to form the planets.

Some more recent theories describe the formation of the planets in terms of magnetic and electric fields as well as gravitational fields. However no theory produced so far is completely satisfactory.

The orbits of all the planets lie very close to

one plane. If you imagine a giant gramophone disc with the sun at the centre, the paths of all the planets would be in or near the disc.

The four planets close to the sun are in some respects similar to the Earth. They all have densities of the same order, i.e. about four or five times the density of water. *Name these four planets.* (8)

Beyond Mars there is a gap in the planetary system. In the gap a large number of very small planets (planetoids or asteroids) have been found. Beyond the planetoids lie the four large planets Jupiter, Saturn, Uranus and Neptune. They have densities of the same order as water. Saturn could in fact float on water! Pluto is the most distant planet yet found.

### Life on the planets

The Earth can support life because it (a) has plenty of water, (b) has oxygen in the atmosphere and (c) is not too hot or too cold. No other planet in the solar system has similar conditions, so that if life exists on another planet, it cannot be the same as life on Earth.

### The inner planets

Only about two-thirds of the surface of Mercury is ever exposed to the sun, and the temperature there sometimes exceeds  $400^{\circ}\text{C}$ . The other side receives no direct sunlight and is always bitterly cold.

Venus is more like the Earth than any other planet. It has a very thick atmosphere. This cloud layer prevents observation of the surface being made. Results obtained from the Mariner IV satellite suggest that the temperature of the planet's surface may be as high as  $400^{\circ}\text{C}$ .

Venus and Mercury show phases like those of the Earth's moon.

Mars is very much smaller than the Earth. Its atmosphere has traces of oxygen and water vapour and large amounts of carbon dioxide. Its daytime temperature is thought to be similar to our own but at night it is very much colder than the Earth.

### The outer planets

The major or outer planets are extremely cold and have atmospheres of gases such as hydro-

gen, helium, methane and ammonia, none of which supports human life.

### The missing planets

Just less than 200 years ago an amateur astronomer was studying the sky with his telescope when he discovered a 'new star'. Yet it could not be a star, for it appeared as a disc rather than a spot of light in his telescope. Herschel thought that it might be a comet, but further investigation showed that it was another planet. Like the other planets it was given a name from Greek mythology: Uranus.

Mathematicians now set to work to prepare tables telling exactly when and where Uranus should be found. They failed. The planet was always ahead of or behind schedule. There then commenced one of the most fascinating detective stories in the history of science.

A French astronomer, Alexis Bouvard, was convinced that a planet beyond Uranus was influencing its movements. In 1841 a young Cambridge student, Adams, worked out mathematically where another planet should be to account for the observed motion of Uranus. He sent the information to the Astronomer Royal, who did nothing about it for months. When at last he did ask someone to look for the new planet it was not recognised.

Meanwhile Leverrier, a French mathematician, had made similar calculations and advised his friend Johan Galle at Berlin Observatory. As soon as he received the information Galle pointed his new telescope in the suggested direction and found the planet within half an hour! It was named Neptune.

But the search was not over. There were still slight variations in the position of Uranus not explained by the presence of Neptune. An American astronomer, Percival Lowell, and many others thought that there might be yet another planet. They searched for years, but not until 1930 was another planet actually discovered. It was found by Tombaugh at the Lowell Observatory. It was named after Pluto, the Greek god of the Underworld.

Out on the fringe, beyond the outer planets, Pluto is much more dense than any of them. It is in fact similar in density to the Earth. Its orbit is tilted out of the plane near to which the



other planets lie. This mysterious little planet is the 'odd man out'.

Some of the planets, then, are bigger, and some are smaller, than the Earth. Some are nearer to, and some are farther from, the sun than we are.

Here is a table showing the approximate sizes of the planets and their distances from the sun.

| Planet               | Distance from the sun in millions of miles | Diameter in thousand of miles | Moons   |
|----------------------|--------------------------------------------|-------------------------------|---------|
| <i>Inner planets</i> |                                            |                               |         |
| Mercury              | 36                                         | 3                             | 0       |
| Venus                | 67                                         | 8                             | 0       |
| Earth                | 93                                         | 8                             | 1       |
| Mars                 | 142                                        | 4                             | 2       |
| <i>Planetoids</i>    |                                            | 0.5                           |         |
| <i>Outer planets</i> |                                            |                               |         |
| Jupiter              | 483                                        | 87                            | 12      |
| Saturn               | 886                                        | 72                            | 9+rings |
| Uranus               | 1,780                                      | 32                            | 5       |
| Neptune              | 2,800                                      | 28                            | 2       |
| Pluto                | 3,700                                      | 4                             | ?       |

**Experiment 3.4.** Construct two scale drawings and label them carefully.

(a) A set of circles representing the size of the planets. Draw part of a circle on the same scale to give an indication of the sun's size compared with the planets.

(b) Part circles (concentric) representing the orbits of the planets.

### Models of the solar system

It is difficult, if not impossible, to grasp the relative sizes of the celestial bodies and the distances separating them. Here is a model which you should study carefully. It is an attempt to give you a picture of astronomical distances. We are going to represent 100,000 miles by 1 inch. The sun will be the size of a football (Fig. 27), the Earth a grain of barley and the moon a pin head. The pin head will be about  $2\frac{1}{2}$  inches away from the barley and their distance from the football will be equivalent to the length of a cricket pitch.

On this scale the most distant planet, Pluto, is just over half a mile from the sun and the nearest star is 4,000 miles away. As the speed of light is 186,000 miles per second, we might

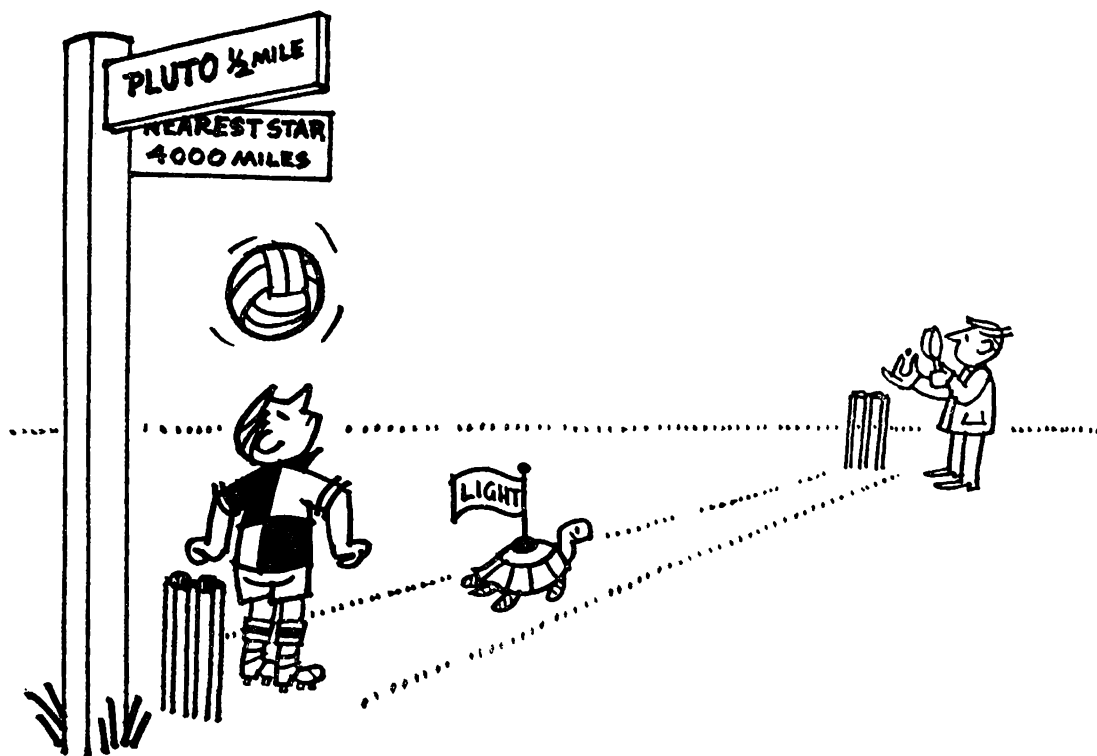


Fig. 27

represent this motion by a super-charged tortoise tearing along at just under 2 inches per second. You can imagine its taking 4 years to reach the nearest star!

When we are thinking of the solar system, models are often much more helpful than diagrams. It should now be obvious that it would be quite impossible to represent the sun, the planets and the stars to one scale on a diagram.

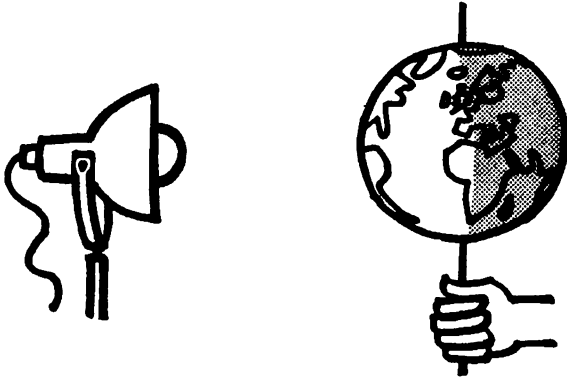


Fig. 28

### Models to build

**Model 3.5.** Here is a model of part of the solar system (not to scale this time) which you should build. Its purpose is to illustrate how the sun, the Earth and the moon move.

First, obtain a sphere to represent the Earth. A toy globe of the Earth (Fig. 28) would be ideal, but anything, from an orange to an old ball, will do. Stick a knitting needle through it and insert the needle in some kind of handle. The sphere should now be able to spin on its axis. If you like, chalk on the ball the continents of the world and mark the spot where you live. Now hold the 'Earth' as shown and use an electric lamp to represent the sun. Best results will be obtained if the bulb is the only source of light in the room and you are standing in front of a dark background. *Why is this so?* (9)

Slowly rotate the 'Earth' and notice how your town is illuminated. *How long does the real Earth take to rotate once on its axis?* (10) *In your model, during what part of the day is there darkness?* (11) *Is this really what happens?* (12)

Suppose now that you move the 'Earth' in a

circle, keeping the 'sun' at the centre and the axis of the 'Earth' upright as shown.

*How long does the real Earth take to go round the sun?* (13) *From your model what can you say about:*

(a) *the length of the days in your town throughout the year?* (14)

(b) *the height of the sun in the sky at mid-day in your town each day throughout the year?* (15)

(c) *the length of the day near the Equator and near the Poles?* (16)

*Do you think that this is a good representation of what really happens?* (17)

Try to find out for yourself by thinking and then by testing your ideas by experiments: (a) how the Earth spins, and (b) how it moves round the sun.

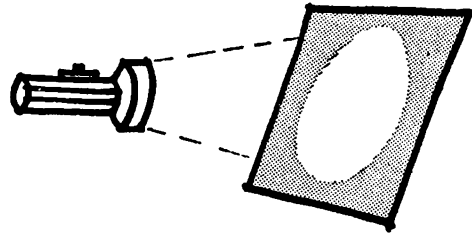


Fig. 29

### Summer and winter

**Experiment 3.6.** Using a focusing torch, or a projector, or a cardboard tube containing a torch bulb, project a beam of light at right angles on to a sheet of paper.

Now gradually tilt the paper (Fig. 29) and observe any change in the area illuminated and the brightness of the illumination.

*When is the paper most brightly lit?* (18) *When is the illumination least?* (19)

Owing to the curvature of the Earth, light from the sun strikes it at right angles near the Equator, but the angle becomes smaller and smaller as we approach the Poles (Fig. 30). *Where would you expect the Earth to be most brightly lit?* (20)

As the Earth's axis is tilted, the northern hemisphere has a greater share of the sun's light than the southern hemisphere when it is in the position shown in Fig. 30.

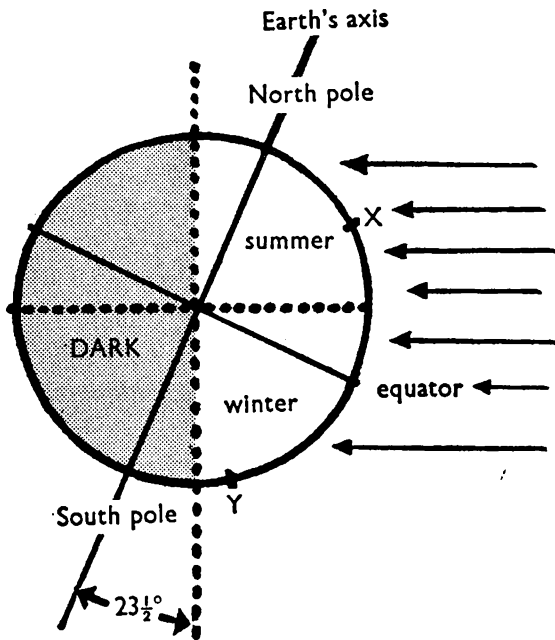


Fig. 30

*X* represents a place which is the same distance from the North Pole as *Y* is from the South Pole. Notice the angle at which the sun's rays are striking those two places. *In which would you expect the temperature to be higher? (21)*

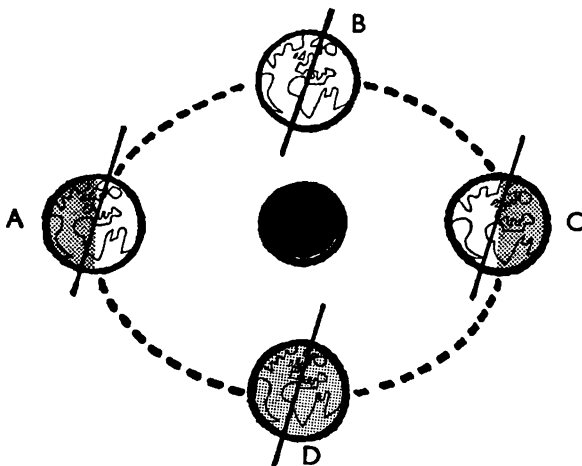


Fig. 31

*State the seasons in the northern hemisphere when the Earth is in the positions A, B, C and D (22) (Fig. 31).*

## Summary

We can summarise the Earth's motion thus:

(1) The Earth, like all large heavenly bodies, rotates on its axis. It makes one complete revolution every 24 hours. This rotation causes day and night but, because the Earth's axis lies at an angle, the lengths of day and night vary throughout the year. The speed of a point on the Equator, due to this spin, is about 500 yd/sec (1,000 m.p.h.).

(2) The Earth also revolves round the sun once every year (365½ days). Its speed in this orbit is about 20 miles/sec.

(3) The Earth, as part of the solar system, is also continually whirling around the centre of the Milky Way at about 140 miles/sec.

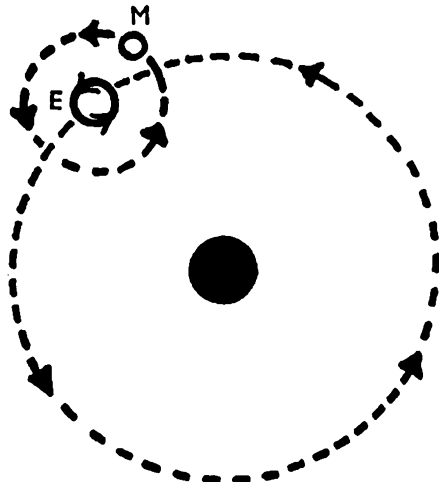


Fig. 32

## The moon

**Model 3.7.** You are now ready to add the moon to your model of the solar system. A table tennis ball mounted on another knitting needle will do nicely.

Here is a plan (a view from the ceiling) of your model (Fig. 32) showing the directions in which the sun and the moon move. To represent their relative movements, move the 'Earth' round the 'sun' parallel to the floor, incline the 'moon's' orbit slightly, and tilt the 'Earth's' axis a bit more. Notice that all three rotations shown



round slowly, holding the ball high enough to allow the light to shine on it all the time. Notice how the ball ('moon') is illuminated by the light from the projector ('sun'). Best results are sometimes obtained if you half-close your eyes.

*Draw a sketch showing the sun and the Earth. Mark on this diagram where the moon will be when it is 'new' and when it is 'full'. (25)*

*What will the moon look like (a) at Spring Tides, (b) at Neap Tides, (c) just before it is eclipsed and (d) just before an eclipse of the sun? (26)*

## The Earth

It is possible that, while the Earth was molten, the different constituents separated, the denser ones going towards the centre. The first surface rocks to crystallise were granite. These gradually grew and formed the continents. The valleys became filled with water, probably as a result of volcanic activity. It is thought that, as the surface rocks crystallised, water vapour and

carbon dioxide were released and rose to the surface. Eventually, enough vapour was released to form a thick cloud round the Earth. This blocked the sun's rays, the atmosphere cooled and the vapour condensed to produce rain. Today, nearly three-quarters of the Earth's surface is covered with water.

The surface of the Earth is forever changing. The present continents have drifted about the Earth's surface. Volcanoes and earthquakes on the one hand, and erosion, due to wind, rain, heat, floods, glaciers, rivers and sea on the other, continue to change the surface of the Earth today.

The energy necessary to move mountains comes from the radio-active breakdown of atomic nuclei. The heat produced normally rises to the surface of the Earth and escapes. If this flow of heat to the surface is hindered by sediment the temperature gradually rises, the rocks melt and the crust buckles.

Geologists read the history of the Earth in the rocks, minerals and fossils. To study the structure of the Earth they use dynamite to send

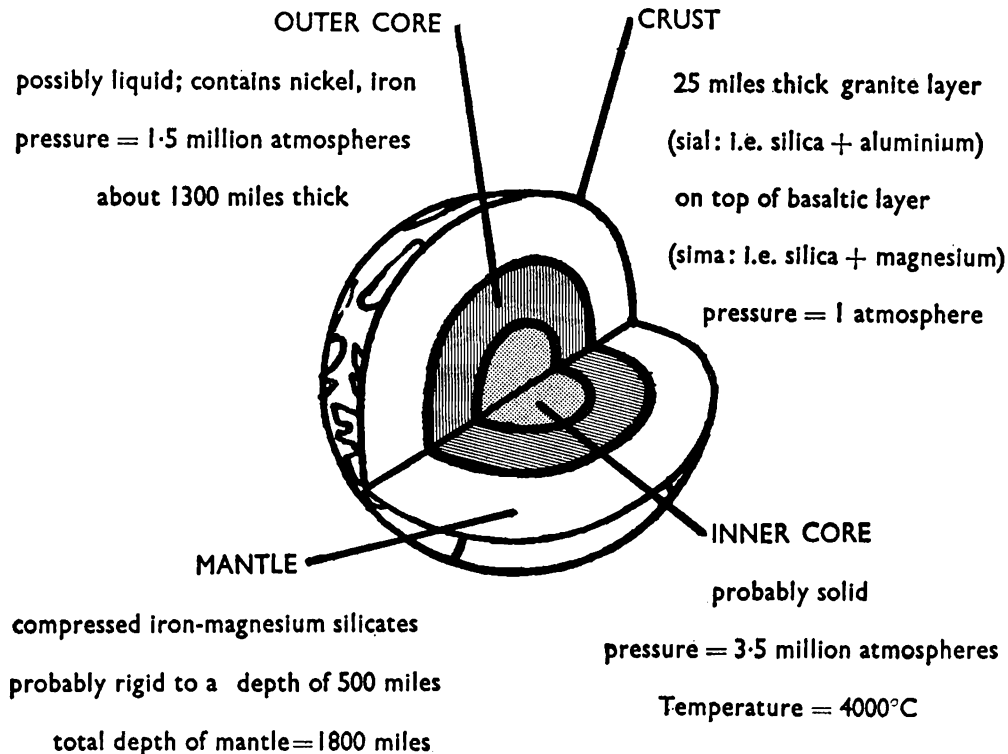


Fig. 35

shock waves through the Earth's crust. Alternatively, they make use of the waves set up by earthquakes to help them investigate the Earth's core. The waves are bent or reflected by different layers in the Earth and they are then detected by a delicate recording instrument called a seismograph.

The Earth is rather like a soft-boiled egg (Fig. 35). The core (yolk) is partly solid and partly liquid. The Earth's magnetic field is thought to be due to electric currents produced in the liquid core of the Earth. The mantle (white of the egg) surrounds the core, and the hard crust (shell) is a thin surface layer.

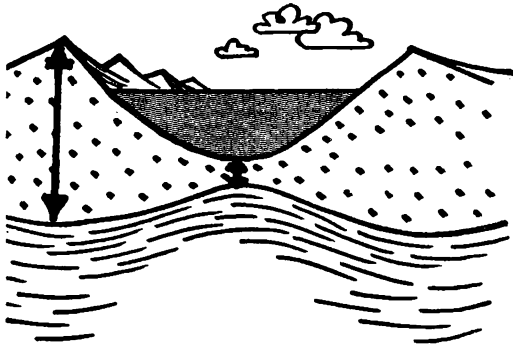


Fig. 36

The crust varies in thickness from 3 to 30 miles (Fig. 36). Below the mountains it is much thicker than it is below the seas.

*Choose an appropriate scale and draw a circle to represent the Earth (diameter = 8,000 miles). On the same scale how would the variations of height on the Earth's surface appear? (27)* The distance from the highest hill (Mount Everest 29,028 ft) to the deepest sea (Marianas trench, off the Phillipines—36,198 ft) is just over 10 miles.

There is a difference of approximately 27 miles in the Earth's diameter at the Equator and at the Poles. *Can this be shown clearly on your scale drawing? (28)*

### Rocks

The rocks of the Earth are oxygen compounds. Silicon is the next most important element after oxygen. Silicon-oxygen compounds are called silicates. Surface rock is about 3 times as dense as water, but as on the average the Earth is about 5 times as dense as water, the Earth's core must consist of material of much greater density than the surface rocks.

Rocks may be grouped under three main headings: (1) igneous, (2) sedimentary and (3) metamorphic.

(1) Igneous rocks. When the molten silicates on the Earth's surface solidified they formed granite and basalt. Such rocks are called igneous rocks.

(2) Sedimentary rocks. Why are rivers in flood often coloured brown?

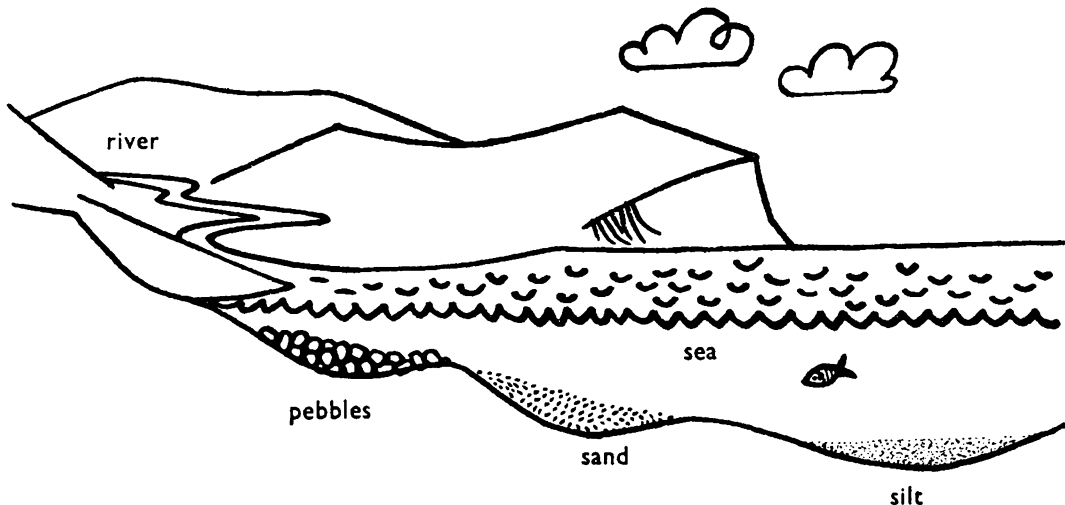


Fig. 37

**Experiment 3.9.** Partly fill a measuring jar with water and pour in a handful of soil and sand. Shake the mixture and allow the jar to stand until the water has cleared. Note carefully how the sediment is deposited.

Over millions of years the igneous rocks were eroded and the sediment was washed down the rivers to the sea where it was deposited in a certain order. (Fig. 37.)

The weight of the sea compressed the mud on the sea bed and gradually layers of rock such as shale, chalk, limestone and sandstone were formed. These are called sedimentary rocks. Upheavals caused those layers to bend and fold and sometimes to rise above the sea level. (Fig. 38.)

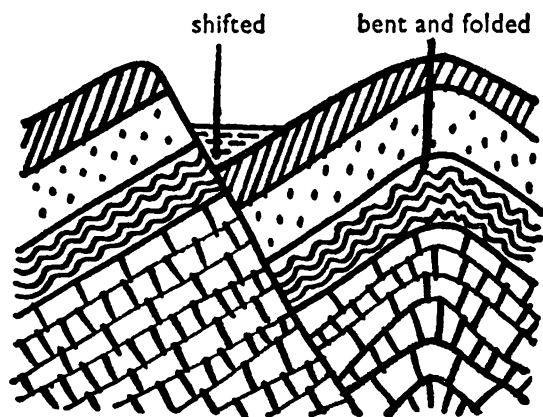


Fig. 38

(3) **Metamorphic Rocks.** Extremely high temperatures and pressures within the Earth change the nature of both igneous and sedimentary rocks. Limestone changes to marble, sandstone to quartzite, and shale to schist. The rocks formed in this way are called metamorphic.

### The Earth's atmosphere

The Earth's atmosphere stretches for hundreds of miles into space. Although it has no definite limit there is very little air beyond a hundred miles or so above the Earth.

Without this atmosphere life on Earth would be impossible. It supplies us with the oxygen we breathe. It protects us from unbearable heat during the day and from freezing to death

at night. It shields us from meteors, cosmic rays and dangerous ultra-violet radiation.

Near the surface of the Earth the main gases present are nitrogen and oxygen. There are also traces of argon, neon, helium, krypton, xenon, carbon dioxide, hydrogen and ozone. The atmosphere also contains water vapour. The force of gravity pulling those gases towards the Earth's surface is responsible for what we call 'atmospheric pressure'. At sea level on the Earth's surface this pressure is said to be 'one atmosphere'.

Weather (clouds, rain, storms, etc.) exists only in the Troposphere (Fig. 39). Pressurised jet planes fly in the Stratosphere to avoid encountering storms. There are high-speed air currents in the Stratosphere which pilots often use to their advantage.

World-wide radio communication is possible because of ionised layers which reflect radio waves (D, E, F<sub>1</sub>, F<sub>2</sub>). Sir Edward Appleton investigated the properties of such reflecting layers in the Ionosphere.

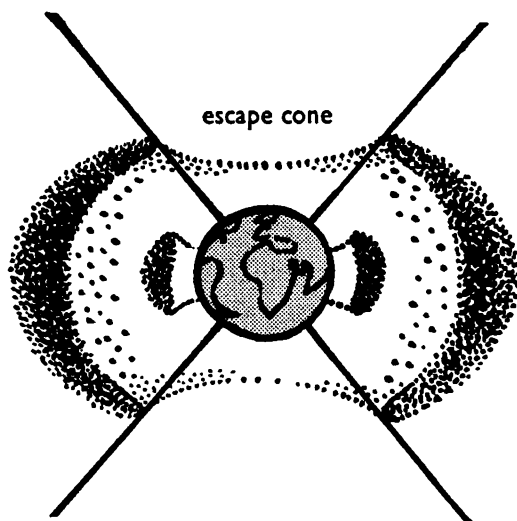


Fig. 40

The Earth is surrounded by two doughnut-shaped regions in which are found electrons and protons (Fig. 40). They are called, after the man who first described them, the Van Allen Radiation Belts. These belts were amongst the first important discoveries made as a result of information obtained from instruments in

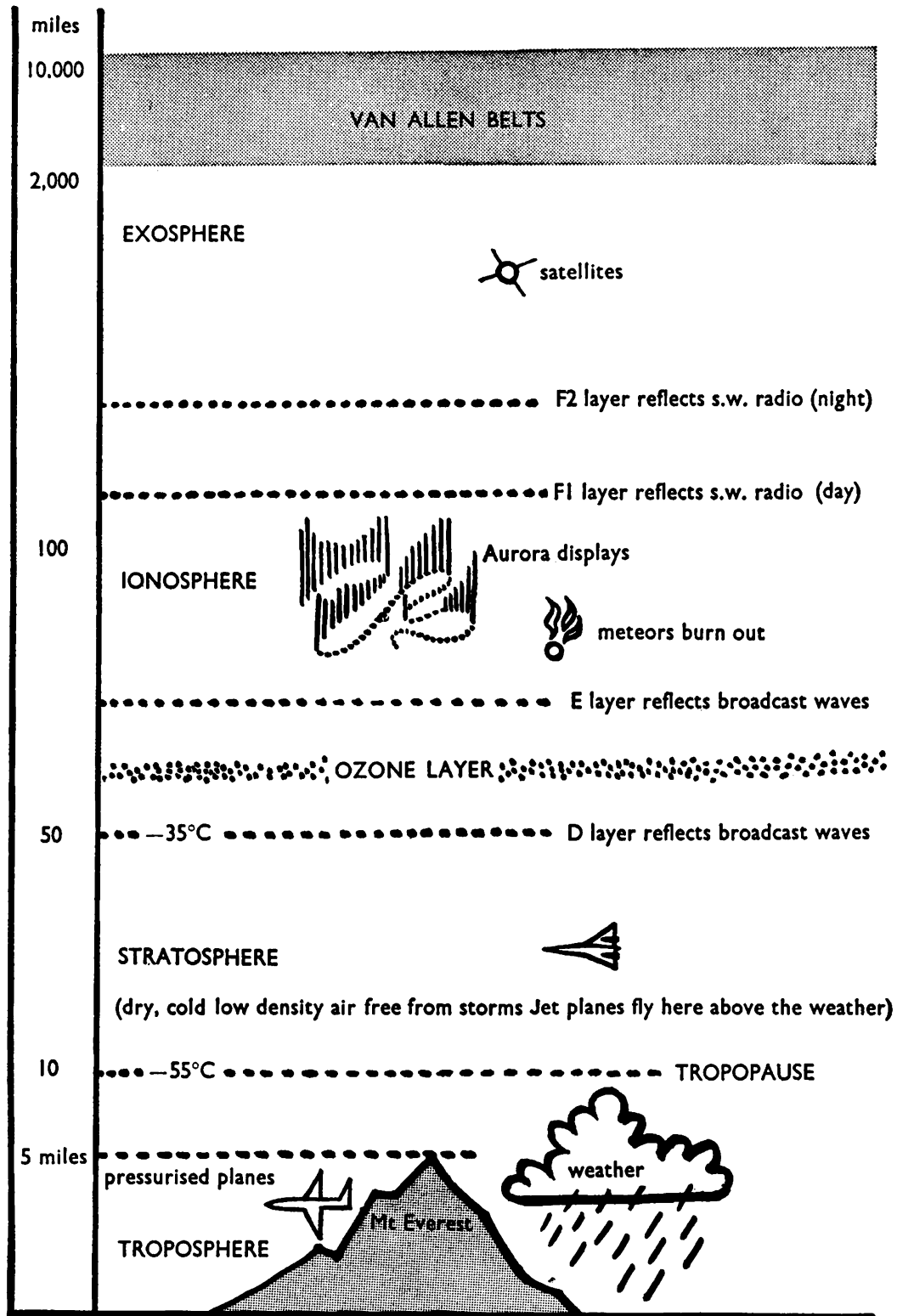


Fig. 39



artificial satellites and lunar probes. The first belt is about 2,000 miles above the Earth and the second about 10,000 miles high. Space

travellers will have to be shielded against the high-energy particles in the Van Allen Belts.

## Visual aids

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Educational Productions issue the following charts, which may be found helpful for this section.

- 'Eclipses of the Sun and Moon'
- 'Solar Planetary System'
- 'Exploring Space' (2 charts)
- 'Time'

Two good filmstrips are also available from Educational Productions. They are

- 'The Solar System'
- 'The Earth's Atmosphere'

The following sound film is available from Boulton-Hawker:

- 'The Birth and Death of Mountains'

# Matter—its forms and changes

## CHAPTER 4

### Sorts of stuff

We all like to put people and things into groups or categories. Having given them labels we feel satisfied that no more need be said on the matter! We do this particularly with people with whom we don't agree. We call them 'capitalists' or 'communists', 'squares' or 'cats'. Some folk judge others by their clothes (or lack of them), their accents, or their possessions. Labelling people in this way is a very dangerous pastime and we usually find that our initial judgements are quite wrong. Of course it is often necessary to group people under certain headings for some particular purpose. For example, an Army commander will use a system of ranks, yet a doctor or psychologist would put

the same men into very different categories.

For thousands of years man has tried to put things into categories. About 350 B.C. Aristotle suggested that every substance (i.e. all matter) was made up of only four basic parts—'the elements' (Fig. 41). Everything, he said, contained all four elements—earth, fire, air and water—but the proportions present were different in different substances. This belief was held for nearly 2,000 years partly because a few simple observations such as burning were thought to confirm it.

Here is an important question which you should consider seriously. *What is matter?* (1) It is not enough to say 'substance' or 'material'. Write down a list of things which you would put under the heading of 'matter' and a list of things which you think do not come under this heading. Now try to think of some test which would distinguish matter from everything else.

We know, today, that many other things exist besides earth, fire, air and water. At least 92 elements have been found in nature and some more have been 'manufactured'. We could therefore put matter into about one hundred categories. Alternatively, we could classify things as living and non-living, or as metals and non-metals. It is, however, sometimes convenient to think of matter in three forms (states). These states are called solid, liquid and gas. Liquids and gases (vapours) are sometimes referred to as fluids. Although it is usually fairly easy to identify the states of a substance there are some borderline cases. A jelly, for example, may be either solid or liquid and it is sometimes rather difficult to tell which. *Suggest some other borderline examples.* (2)

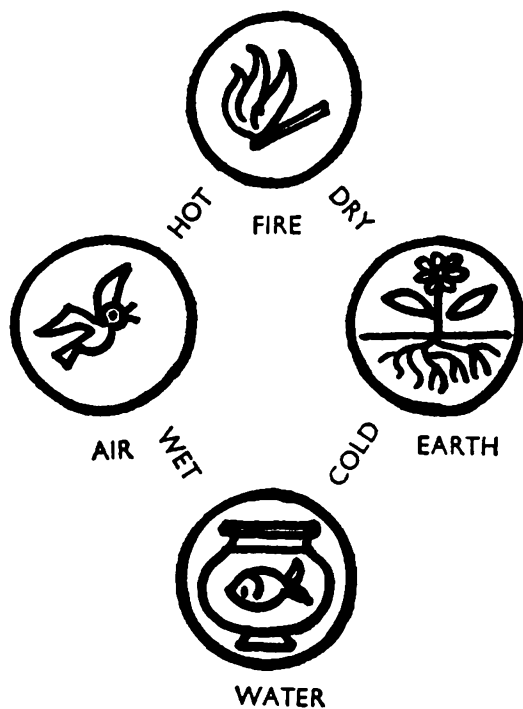


Fig. 41

### Changes in matter

Substances can be altered in various ways. For convenience we will think of these changes

under three headings, although sometimes the first two cannot be clearly distinguished.

- (1) Physical changes. (What you do in the physics lab.)
- (2) Chemical changes. (What you do in the chemistry lab.)
- (3) Nuclear changes. (What you don't do!)

## (I) Physical changes

We will consider five physical changes, all of which may be reversed.

- (1) Change of state.
- (2) Thermal expansion.
- (3) Dissolving solids in liquids.
- (4) Magnetisation.
- (5) Charging electrically.

### Physical change (1) Change of state

**Experiment 4.1.** Put a handful of broken ice into a beaker or can. Read the temperature. Leave the ice for a while until it starts to melt. Again measure the temperature. Now heat the water and continue to read the temperature at regular intervals. Does the temperature go on rising as long as you heat the water? Hold a test tube containing cold water above the boiling water and record what you see.

**Experiment 4.2.** Devise experiments which enable you to answer the following questions.

(a) At what temperature does:

- (1) ice melt?
- (2) naphthalene melt?
- (3) paraffin wax melt? (approximate temperature)
- (4) water boil?

(b) How does the addition of salt to water affect:

- (1) its freezing point?
- (2) its boiling point?

*Explain the gap between the spout of the kettle and the 'steam'. (3) (Fig. 42.) Why is 'steam' printed here in inverted commas? (4) You can also see the result of condensation on a cold bath tap. Why is there no moisture on the hot tap? (5)*

If the condensed water vapour were collected and placed in a refrigerator it could be frozen to ice again.



Fig. 42

A substance, then, may be changed from solid to liquid or liquid to gas by heating it, that is, by giving it more energy. The reverse processes are effected by cooling the substance, that is, by taking heat energy away from the substance.

*Which of the following temperatures is different from the other two? (i) boiling point, (ii) melting point, (iii) freezing point. (6)*

*How does the addition of anti-freeze affect the freezing point of the water in a car radiator? (7) Why is it not necessary to add anti-freeze to a car battery, the petrol or the oil? (8)*

*We usually think of metals as solids. Can you name an exception? (9) Where, on Earth, will water normally be a solid? (10)*

Elements and pure compounds melt at one particular temperature (the melting point) and solidify at the same temperature. Many substances, such as glass, do not. The various constituents of glass have different melting-temperatures so that when heated the glass becomes plastic for a time. It is this property of glass which enables glass blowers to mould the glass into various shapes. By finding the different temperatures at which the constituents of a liquid mixture boil, chemists can often discover what substances the mixture contains. The temperature at which an element or pure

**Physical change (4) Magnetisation**

Certain substances such as iron, steel, nickel and cobalt can be magnetised and demagnetised. This also is a physical change.

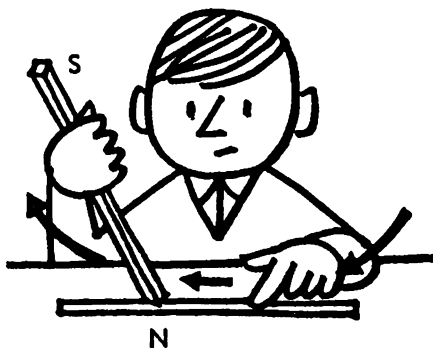


Fig. 45

**Experiment 4.9.** Take a steel knitting needle and see if it will pick up steel pins or iron filings. Now stroke the needle several times in one direction using an Alnico bar magnet (Fig. 45). Can you guess why Alnico was so named? Can you now pick up any pins or filings? What have you done to the needle? Can you discover a way to demagnetise it? See what happens when you bring two *north poles* and then a *north* and a *south pole* together.

*What is a compass needle? (12) Why do you think that one end of a bar magnet is called the north end or pole? (13)*

**Physical change (5) Charging electrically**

**Experiment 4.10.** Try to pick up small pieces of paper with a ball pen before and after rubbing its barrel on your sleeve. The pen becomes electrically charged. Can you discharge the pen? Repeat this experiment with other substances and make a list of those which give the best results.

**Demonstration 4.11.** See the spark produced by a Van de Graaff or Wimshurst machine (Fig. 46). It results from the large voltages developed by those machines. Can you think of any ways of producing small electric sparks?

The five physical changes considered were (1) change of state, (2) thermal expansion,

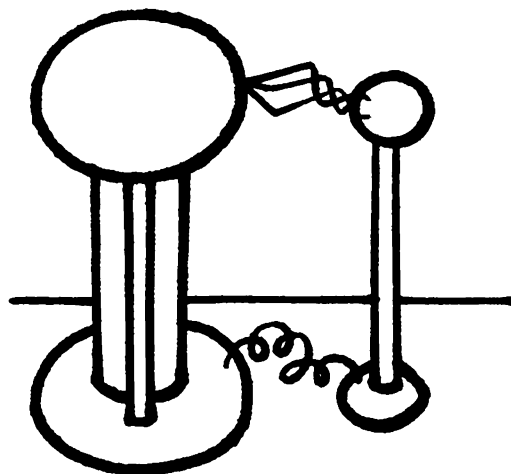


Fig. 46

(3) dissolving solids in liquids, (4) magnetisation, (5) charging electrically. No new substance was formed during those changes.

**2. Chemical changes**

In the physical changes discussed it is usually fairly easy to return to the original form. For example a magnetised bar can be demagnetised or a gas cooled down to its liquid state. Try some of the following experiments and note the results.

**Demonstration 4.12.**

- (a) Burn a piece of paper.
- (b) Hold a piece of magnesium ribbon with a pair of tongs and heat it in a bunsen flame.
- (c) Heat some mercuric oxide in a test tube. Is the change of colour a chemical or physical change? Note any deposit on the sides of the test tube. How would you test to see if oxygen was being released?
- (d) Heat an inverted crucible lid until it is just red hot. Remove the bunsen burner, drop a large crystal of ammonium dichromate on to the lid and observe the result in a darkened room.
- (e) Place side by side open bottles of concentrated hydrochloric acid and ammonia solution (0.88). Two vapours combine here to form white fumes, that is, tiny solid particles of smoke.
- (f) Pour about  $\frac{1}{2}$  in of thermite (a 50/50

mixture of aluminium dust and ferric oxide) into a crucible standing on an asbestos board. Put a little sodium peroxide on top and insert a magnesium ribbon fuse. Light the fuse and observe from a safe distance.

(g) Prepare a mixture of powdered iodine and powdered aluminium (roughly 50/50). Place a heap of the mixture on an asbestos plate and pour one drop of water into a 'crater' on top of the heap. Stand clear.

(h) Throw a teaspoonful of finely powdered magnesium metal into the flame of a bunsen burner.

In each of the above experiments the substances are chemically changed into different substances in such a way that the original material cannot easily be recovered if at all. Some chemical changes, however, can be reversed.

Only when you have investigated the way in which substances are built up from the atoms of different elements can you understand chemical changes. Look at a Periodic Table and see how many elements you can name from the symbols

there. (Excellent charts are available from The International Nickel Co. and Mullard.)

### 3. Nuclear changes

The atoms of certain elements such as uranium and radium give off particles, and in so doing change into other substances of their own accord. Such elements are said to be radio-active, and the change which takes place is called nuclear change.

The luminous numbers on a watch can be seen in the dark because of tiny nuclear explosions in the radio-active paint. Particles are expelled from the radio-active material in the paint with so much energy that they produce flashes of light when they strike the fluorescent material which is also present in the paint.

If you examine such numerals in the dark using a powerful magnifying glass or low-power microscope you may see the flashes of light. You will, however, have to allow your eyes to become accustomed to the dark first. This may take about ten minutes.

# MOLECULES

## CHAPTER 5

### Seeing is believing

Two thousand years ago Doubting Thomas said 'Unless I see . . . I will not believe.' We all like to be convinced of the truth of something by seeing it. 'I'll believe that when I see it myself,' we often say.



Fig. 47

Look at the three people walking through this tunnel (Fig. 47). *Which figure is the tallest?* (1) Now measure the drawings yourself.

What we perceive is affected by what we have learned through experience. We know that the sides of tunnels appear to converge in the distance, and we therefore assume that the distant figure is tallest.

Have you ever looked at a full moon near the horizon? *How does it compare with the apparent*

*size of the moon when it is high in the sky? (2) Can you think of a simple way in which you could test whether or not this is an optical illusion? (3)*

Read the title of this chapter from a distance and you will see that the letters appear normal. When you study them closely you see that they are incomplete.

These and many other optical illusions depend on the fact that to some extent we see what we look for. In a sense we see what we believe rather than believe what we see! When making scientific observations care must be taken to keep the effects of optical illusions as small as possible. Seeing is not, however, the only way in which we obtain information about the physical world. We can taste and touch.

Blindfold a friend and try out the following experiments.

**Experiment 5.1.** (a) Place your friend as far away from walls as possible. Snap your fingers at a point which is the same distance from each of his ears, for example, immediately above his head. Ask him to point to the source of the sound.

(b) Hold a slice of pear immediately below his nose and give him a slice of apple to eat. Ask him what he tastes.

(c) Touch the back of his hand or neck with a piece of ice which has been carefully dried and ask him to describe the sensation.

(d) Ask your friend to cross his first and middle fingers. Gently move a pencil point between his fingers and ask how many pencils are touching him. Alternatively ask him to rub the point of his nose with his crossed fingers and then to describe the sensation.

(e) For this experiment you can remove your friend's blindfold. Ask him to place his left hand in a basin of hot water and the other hand in a basin of cold water. He should leave them

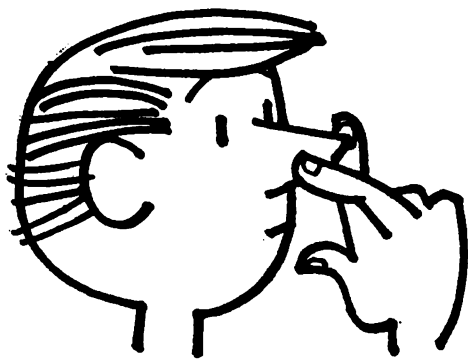


Fig. 48

there for about half a minute and then immediately transfer his hands to a basin of tepid water. Ask him to describe what each hand 'tells' him.

(f) Finally, here is an experiment which you can try yourself. Close one eye and point to an object on the wall. Now open that eye and close the other. Are you still pointing at the object? When reading instruments you must beware of this trouble. It is called parallax.

*Which of the following conclusions would you draw from these experiments? (a) Our senses always mislead us. (b) Our first impressions may be wrong and we would be wise to check them using a totally different method if possible. (c) We can rarely trust what we see, hear, smell, touch or taste. (4)*

Fortunately, optical and other illusions are the exception rather than the rule. Nevertheless observations of all kinds should be checked wherever possible.

## Detectives on the trail

Does anything exist which cannot be detected directly by the senses? If you cannot hear it: if you cannot see it or smell it, touch it or taste it—is it real? How about anger, affection, air and atoms? Although we cannot see those things we can see what they do. The first two are not, of course, physical, although it would be misleading to say they were not real. Many things are recognised only by their effects. *How could you tell if there were (a) radio waves (b) a magnetic field or (c) radio-active fall-out in your home? (5) What would you say to someone*

*who said that he did not believe that air or electricity existed because he had never seen them? (6)*

If you want to be a scientist you must become a detective. Collect all the clues you can and use them to track down the culprit. You may find that he is invisible, dumb and odourless, but somewhere he may have left fingerprints, footprints or vapour trails. Follow them; they may lead you to amazing discoveries.

## Molecules

Take a piece of wood and halve it. Now halve the halves, then halve the quarters and so on. Could you go on doing this for ever? Obviously not, for soon you would not be able to cut or even to hold the pieces. Now imagine some microscopically small dwarf, capable of becoming smaller and smaller, carrying on the halving operation when you left off. Could he go on for ever?

Over 2,000 years ago two Greek philosophers answered 'No'. They said that there is a limit to the size of the pieces that exist in nature and suggested that all matter is made up of tiny particles which themselves cannot be broken up. Their idea was not accepted and for centuries it was thought that it was possible, at least in theory, to go on indefinitely breaking things into smaller and smaller bits.

If matter is made up of tiny particles they must be smaller than anything which can be seen even with the most powerful optical microscope. To find out if there really are such particles we must therefore look for other clues.

### Experiment 5.2.

(a) Study a selection of crystals. What can you say about their shapes?

(b) Clean a zinc strip or rod with emery paper and leave it for a few days in a solution of lead nitrate. Observe the growth of lead crystals as they form a 'lead tree'.

(c) Dissolve as much lead iodide as possible in a test tube of boiling water. Allow the solution to cool, and observe the formation of crystals by placing the test tube in a beam of light.

(d) You can grow a magnificent copper sulphate crystal in the following way. Place a test tube of hot water in some boiling water and add copper sulphate to the test tube until a saturated solution is obtained. A drop of sulphuric acid should also be added. Filter the solution into a crystallising dish and leave it to evaporate until dry. Select the best crystal formed and tie it to a long (preferably blonde!) hair. Suspend the crystal in another basin filled with a saturated solution of copper sulphate and leave it for a week or more.

(e) Take a crystal of Iceland spar (calcium carbonate) and break it gently with a hammer. Now break the pieces. Study the smallest fragments under a microscope. What do you observe?

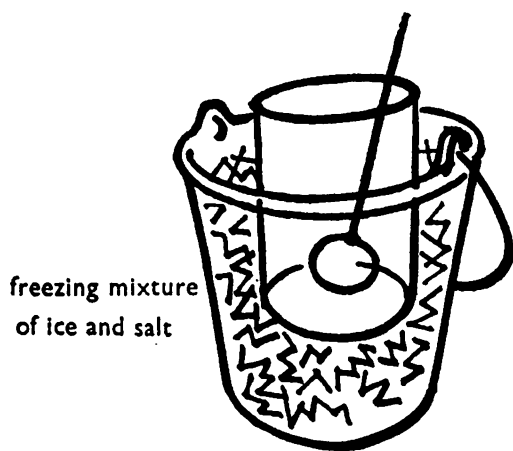


Fig. 49

(f) Place a can in a bucket containing 'dry ice' or a freezing mixture (Fig. 49). Produce a soap film on a loop of wire, lower it into the can and watch what happens.

(g) This is the most exciting experiment of all. Melt a little Salol on a microscope slide and place a speck of powdered Salol on it. Examine this with a microscope. With luck you will be able to watch a single crystal growing rapidly.

Remember that what we are trying to discover is whether or not matter is made up of many little pieces all of which we might assume to be identical for a given substance. *Do you think the regular shapes of crystals provide a possible clue? (7)*

### Demonstration 5.3. Brownian movement.

(a) This effect was originally discovered by a Scottish botanist, Robert Brown. He found that small solid specks suspended in a liquid were continually dancing around. This experiment can be repeated using a very dilute solution of Indian ink, Aquadag, rutile or even school milk! Place a small drop of the solution on a microscope slide and examine it under a high-power microscope. (Aquadag is available from A. H. Baird.)

A similar effect can be observed without the aid of a microscope using some dandruff lotion ('Banish') in a beaker. If this liquid is illuminated by a projector and a magnifying glass used the effect is clearly visible.

(b) Several manufacturers now supply smoke cells which can be used very simply to study Brownian movement in smoke-filled air using a low-power microscope.

In the above experiments the tiny solid pieces are seen to move in liquids and gases. The following model may help you to see why they are dancing around.



Fig. 50

*Model 5.4.* Pack as many pupils as possible round a table (Fig. 50). A billiard table would be fine, but if your lab doesn't possess one a



bench will do. Each pupil should be armed with a few marbles. A fair-sized cork block should be placed in the centre of the table. The object of the game is to keep marbles moving all over the table in different directions. Some will no doubt strike the block, which should move. If the block is painted with fluorescent paint and the table illuminated solely by ultra-violet light a more striking result is obtained.

To avoid confusion between the ink or smoke particles (represented by the cork) and the tiny fluid particles (represented by the marbles) we will refer to the fluid particles as 'molecules'. This is merely a label at this stage.

The haphazard way in which the solid particles of ink or smoke dance around in the Brownian movement experiments suggests that they are being pushed first one way and then another. If these solid specks are being pushed around by molecules then the molecules must be very small as they cannot be seen. *What would this suggest to you about the speed of those molecules?* (8) *If there were an infinite number of molecules (i.e. continuous matter) all pushing the speck from all sides and all having the same speed what would you expect to happen to the speck?* (9)

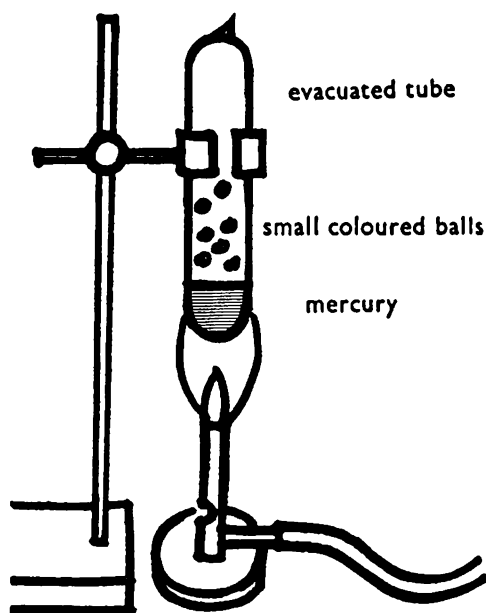


Fig. 51

**Demonstration 5.5.** An evacuated tube contains mercury on top of which rest some small coloured beads. Gently heat the mercury with a Bunsen burner (Fig. 51). Watch the antics of the beads. Do you think this suggests the presence of mercury molecules? Why? What effect has the heat energy had on those mercury molecules?

(Beware of jumping to conclusions—this is not Brownian movement. The beads are jumping about because of the bombardment by large numbers of molecules all moving in the same direction as the mercury evaporates from the surface.)

An excellent piece of apparatus for this demonstration has been developed by Griffin & George.

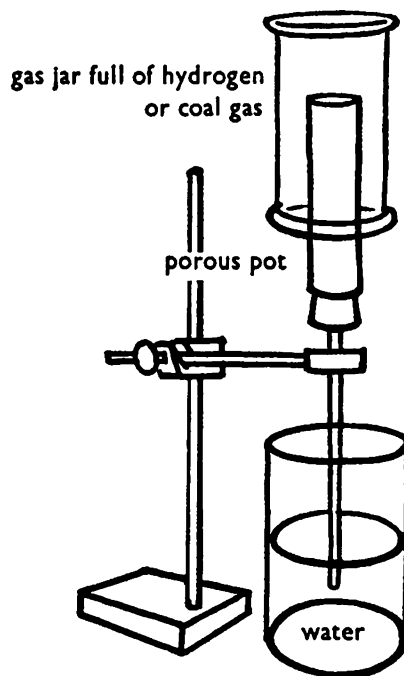


Fig. 52

#### **Demonstration 5.6.**

(a) Fix up a new porous pot for a Daniell cell as shown in Fig. 52. Fill a gas jar with hydrogen or coal gas and lower it over the porous pot. Has hydrogen gas entered or left the porous pot? Does this suggest hydrogen molecules exist? If so why do they cause the result we see?

(b) Repeat the last experiment using carbon dioxide gas, which is denser than air and therefore sinks in air. Make any modifications to the apparatus which you think are necessary. What does the result suggest about carbon dioxide molecules?

### The birds and the bees

In the first of these experiments hydrogen molecules entered the porous pot. *Does this mean that hydrogen molecules are small enough to go through the pot whilst air molecules are too big?* (10) *If this is so how do you explain the result obtained with the carbon dioxide?* (11) It is true that the hydrogen molecules are smaller than those of the other gases but the pores in the pot are considerably bigger than either. If hydrogen molecules were the size of bees, air molecules would be about the size of birds and the holes in the pot might be as big as the Mersey Tunnel. Gas molecules are passing in and out of the porous pot all the time. If, however, the gas molecules outside are moving more quickly than those inside the pot, more will be likely to move in than out. *Does this give you a clue to the speed of hydrogen, air and carbon dioxide molecules?* (12)

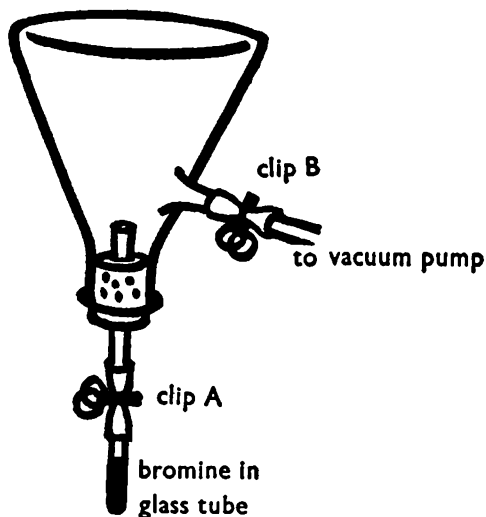


Fig. 53

### Demonstration 5.7: diffusion in a gas

(a) Using the apparatus shown in Fig. 53, open clip B and evacuate the flask with a vacuum pump. Close clip B and open clip A,

allowing the bromine to evaporate into the flask. What does this experiment tell you about the speed of bromine gas molecules? Repeat this experiment with another flask filled with air. Can you explain the difference in the observed result?

(Take great care with bromine and always keep an antidote at hand when using it. A bromine burn should be treated with a solution of sodium bicarbonate followed by an application of benzene or alcohol.)

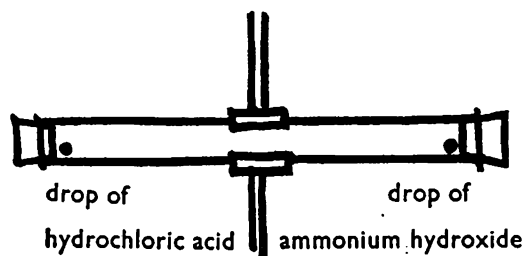


Fig. 54

(b) In this experiment you can compare the speeds of the molecules of two different gases in air. Place a few drops of hydrochloric acid at one end of a two-foot tube and a few drops of ammonium hydroxide at the other end. (Fig. 54.) Insert a rubber stopper at each end. When the molecules meet they combine to form a white powder (smoke). Notice *where* the smoke ring is formed. What does this tell you about the speed at which these molecules travel in air? Why did they take so long (a few minutes)?

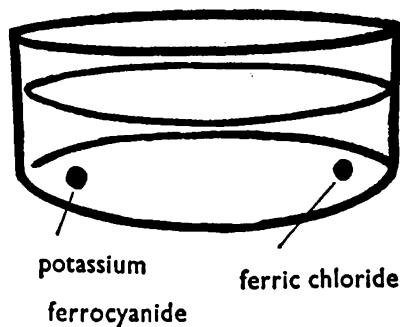


Fig. 55

### Experiment 5.8: diffusion in a liquid

(a) Crystals of potassium ferrocyanide and ferric chloride are dropped into water in a

crystallising dish (Fig. 55). After a while a dark blue patch will be observed. Why?

(b) Alternatively, drop crystals of copper sulphate into a measuring jar full of water and leave it for a few days, examining it from time to time.

### Spaces between molecules

The last few experiments have shown that if molecules exist in liquids and gases they are always on the move. *If this is so do you think they will be packed tightly together or will there be spaces between them?* (13) Try the following experiments to see if your answer was correct.

#### Experiment 5.9.

(a) Measure out 50 cm<sup>3</sup> of water and 50 cm<sup>3</sup> of pure alcohol. They should be at room temperature. Mix the two liquids and allow them to cool to room temperature again. Now measure the combined volumes.

(b) Take a tumbler full to the brim with water and then add as much salt as possible without the liquid overflowing.

**Model 5.10.** Here is a model which might help you understand the last experiment. Take a tumbler filled with glass beads and add sand to it. Where does the sand go?

**Demonstration 5.11.** Can light pass through a solid metal? Take a thin gold leaf and mount it in a 35-mm slide-holder. Slip the slide into a projector and note the result. What colour of light passes through?

### Size of molecules

Here are a few experiments which should give you some idea of the size of molecules if they exist!

**Demonstration 5.12.** Take 1 g of fluorescein and pour it into 99 g (99 cm<sup>3</sup>) of water. Now take 10 cm<sup>3</sup> of this solution and add it to 90 cm<sup>3</sup> of water. Repeat this dilution process until you can no longer observe the presence of fluorescein in the solution. If this experiment is conducted in ultra-violet light the effect is more striking. Detergents such as Daz may be used instead of fluorescein. What is the weakest solution you can obtain in which fluorescein can still be detected? Express your answer as one part in

ten to the power  $x$  ( $1:10^x$ ) putting in the value of  $x$ .

**Demonstration 5.13.** Pour a little household ammonia or ether into an evaporating dish and leave it. Alternatively turn on the gas tap for a very few seconds. What do you deduce from the results detected over a wide area? Why can you smell camphor or naphthalene?

**Demonstration 5.14.** Fill one balloon with air and another identical balloon with coal gas. A plastic inflator such as those used to blow up small rubber rafts is ideal for this purpose (5s. from Woolworths). Leave the balloons overnight and compare their sizes the next day. If the gas molecules pass through the spaces in the rubber what can you say about the size of these molecules?

**Model 5.15.** Pour some fresh lead shot on to a flat tray so that the whole tray is not completely covered. How many layers of shot lie on that tray?

**Demonstration 5.16.** Prepare a solution of oleic acid and alcohol (1 part of oleic acid to 200 parts of alcohol). Take a shallow dish or tray which is at least 18 in square and fill it with clean water. Allow the water to become still and then sprinkle lycopodium powder or chalk dust thinly on the surface. Place a drop of the prepared solution in the centre of the dish and observe the result. Why does one drop of solution not cover the whole surface of the water? Does this suggest that the oleic acid (oil) film is made up of particles (molecules)? If so, what would be the thickness of the thinnest possible oil film?

If this experiment is repeated using alcohol alone it will be seen that it soon evaporates or dissolves in the water. The alcohol in the solution will therefore evaporate or dissolve so that the film with which you are left is really oleic acid. Assuming that this layer is only one molecule thick an estimate of the maximum size of the molecules can be found. You should make this calculation later once you have had some experience of measuring areas and volumes. Molecules may measure one ten millionth ( $10^{-7}$ ) of a centimetre.

Taken by itself none of those experiments would be likely to convince a scientific detective

that the culprit was a particle. Nevertheless when we consider all the clues which we have discovered in those experiments it seems reasonable to assume

(a) that solids, liquids and gases are all made up of very small particles. We call them molecules;

(b) that those molecules are continually moving about, and

(c) that the molecules speed up when they are heated.

### Photographing molecules

There is one further piece of evidence which you cannot obtain in a school laboratory. It is an actual photograph of molecules. While molecules cannot be seen even with the most powerful optical microscope it is possible to 'see' large molecules with an electron microscope (Fig. 56), 'see', that is, in the same sense as you can see someone on a television screen.

An even more powerful microscope called the *field-ion microscope* has been used to produce photographs which show the arrangements of atoms in the tip of a tungsten needle. The picture on the cover of this book (reproduced by permission of the United States Information Service) shows such a photograph.

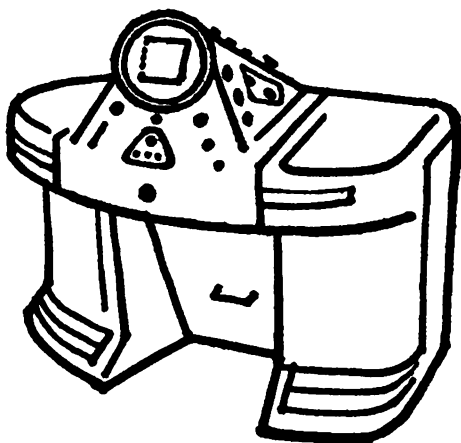


Fig. 56

## Molecules help to explain

### (1) Kinetic theory

Over 200 years ago a Swiss mathematician, Daniel Bernoulli, suggested that gases consist

of millions of minute particles. Gas pressure, he claimed, was caused by these particles bombarding the walls of their container. As the gas was heated so the speed of the molecules increased and the pressure became greater. *What is the meaning of 'kinetic'?* (14) It comes from the same root as kinema or cinema.

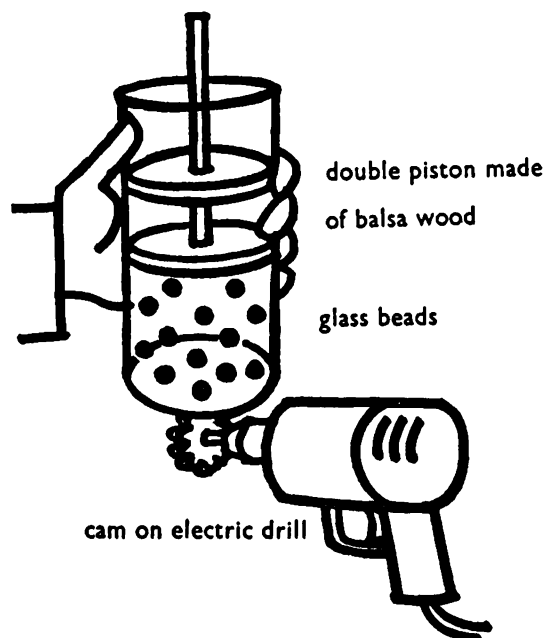


Fig. 57

**Model 5.17.** Here is a model to illustrate the kinetic theory of gases. Take a Perspex container and make a balsa-wood piston to fit loosely into it (Fig. 57). Use glass beads to represent the molecules. An electric hand drill fitted with a cam will produce the necessary 'molecular movement'. By pressing the container on the cam the speed of the 'molecules' will be increased and a greater pressure applied to the piston.

### Solid

In a solid the molecules are tightly held together by strong forces of attraction. They are continually vibrating backwards and forwards but never leave their own backyard.

### Liquid

When a solid is heated the molecules vibrate more energetically until they have so much

energy that they burst open the back gate and move freely along the street. They are, however, still attracted to each other so that although they move around they never leave their friends in the street.

### Gas

If the molecules are now given even more energy by heating them still further they become highly energetic and completely discontented. They leave home for the far country. The forces of attraction between them now are so small that they can usually be ignored. The molecules fly around on their own and bump into one another less frequently.

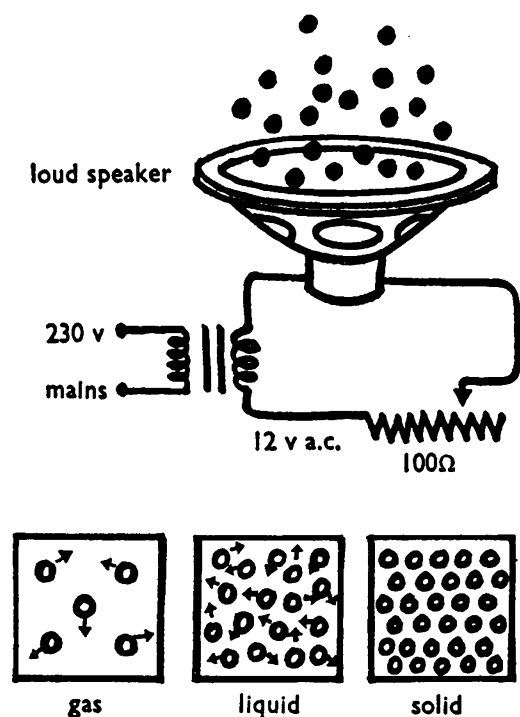


Fig. 58

**Model 5.18.** Here is a model which may help you to picture what is happening. Using coloured beads, mustard seeds or polystyrene beads to represent the molecules you can illustrate the three states of matter as follows.

Take an old loudspeaker and connect it through a variable resistance of 100 ohms to a 12-volt A.C. supply. With a small current flowing through the speaker the beads will

vibrate. By gradually increasing the current the beads will vibrate more and more violently until they move about but still remain in the speaker cone. Which state of matter does this represent? By increasing the speaker current still further the beads will fly off into the air.

Many interesting variations are possible with this apparatus. (a) Try burying a table tennis ball in the beads before 'heating' them to the 'liquid' state. (b) If steel ball-bearings are placed on the rapidly vibrating beads (liquid state) they will sink to the bottom. (c) A large bell jar placed over the speaker may be filled with flying beads (gas).

An Advance vibrator fed from 6-volt A.C. may be used to drive a piston in a glass or Perspex tube and will produce the same type of result as that illustrated above.

The above model is not an experiment. It is merely an illustration. Be careful what conclusions you draw from a model of this kind. For example you cannot say that molecules are little balls or that they are solid or brightly coloured. The results of many experiments show that molecules move more rapidly when they are given extra energy (heat). In the solid state molecules vibrate but do not move around. In liquids they are less closely packed together and move around more freely. Gas molecules are almost completely free and are very much farther apart. The speed of the molecules increases with the temperature. This model is intended simply to illustrate those points.

### (2) Molecular forces

Molecules attract each other, but if they come very close together other forces come into play so that the molecules push each other away. The force of attraction between the molecules of one substance is called cohesion. So strong is this cohesive force in, say, one-inch steel cable that the cable is capable of lifting a railway engine. *Is cohesion strongest in solids, liquids or gases?* (15)

Molecules of some substances are, however, attracted more strongly by molecules of another substance. The force of attraction between molecules of different substances is called adhesion. The molecules of glue, an adhesive,

are strongly attracted to the molecules of wood. Similarly oil molecules are strongly attracted to molecules of steel. Lubrication of machine bearings depends upon this adhesive force which keeps an oil layer between the surfaces of the bearings. *List some of the things which depend on (a) cohesion and (b) adhesion. (16)*

**Experiment 5.19.** Rub zinc stearate over one of your hands and then plunge both hands into water. Remove your hands from the water and examine them. Explain the result in terms of forces of adhesion and cohesion.

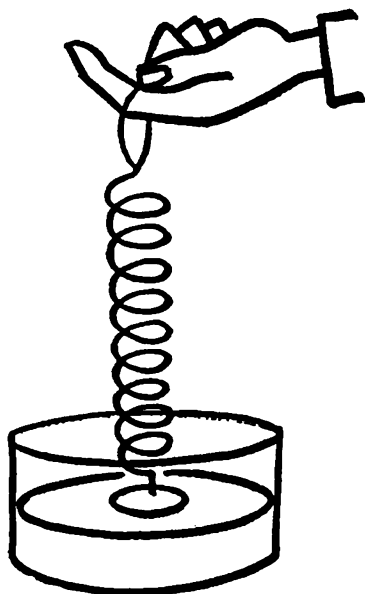


Fig. 59

**Experiment 5.20.**

(a) Fix a light spring or rubber band to the centre of a small glass disc, using sealing wax or glue. Gently lower the plate until it lies flat on the surface of clean water (Fig. 59). Gently pull the spring upwards until it is free from the water. Does water stick to water (cohesion)? Does water stick to glass (adhesion)? State which of those two forces is greater, giving a reason for your answer. Repeat this experiment using mercury instead of water. What differences do you observe and what do they suggest?

(b) Examine the surfaces of water and mer-

cury in glass tubes. Can you suggest why they are different?

### (3) Surface Tension

**Demonstration 5.21.** Drop aniline into a beaker full of water which is being gently heated and examine the shape and size of the drops formed. Use aniline with great care as it is a dangerous liver poison which can be absorbed by the skin.

**Experiment 5.22.**

(a) Pour some water into a test tube and pour in a few drops of olive oil. Now add some industrial methylated spirit until the oil forms into drops in the mixture. Examine the shape and size of the drops.

(b) Blow a soap bubble using a thistle funnel or clay pipe. Watch what happens to the bubble if you stop blowing it. With the bubble still attached to the pipe, place the open end of the pipe close to a candle flame and explain what happens.

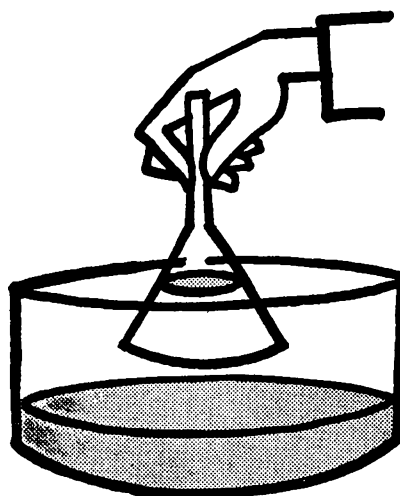


Fig. 60

(c) Make a solution of 50 per cent water and 50 per cent Stergene. Wet the inside of a filter funnel and dip it into the soap solution so that a soap film is formed across the wide end. Watch what happens to the film when the funnel is held as shown in Fig. 60. Can you explain what you see?

(d) Observe the shape of drops of water

falling from a dripping tap. Study small drops of mercury on glass or water on wax.

(e) Pierce four small holes about a quarter

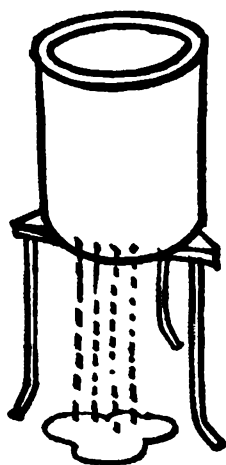


Fig. 61

of an inch apart at the bottom of a tin can. Now fill the can with water, thus producing four water jets. Pinch the jets together with your fingers so that the water now issues in a single stream. Is the surface area of the single stream greater or less than the total surface area of the four jets?

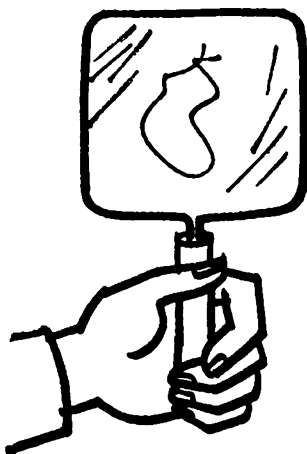


Fig. 62

(f) Take a square wire frame and a much smaller loop of fine thread (Fig. 62). Dip the wire into a soap solution and collect a soap film on the frame. Throw the thread loop on to the

film and puncture the film inside the loop using a heated needle. Note carefully the shape of the loop now.

These experiments suggest that the surfaces of liquids (in the above examples they are in the form of drops or films) behave in a peculiar manner. Try to find out how lead shot is made. (17)

Do the above experiments suggest that the forces (tensions) at liquid surfaces act so as to make the surface areas of the liquid as big as possible or as small as possible? (18) It may help you to answer this question if you conduct a simple investigation.

**Experiment 5.23.** Take a loop of thread and lay it on a sheet of graph paper. Arrange it so that the loop contains the greatest number of squares. What is its shape when the area (number of squares) is greatest? Can you guess what the corresponding shape will be in three dimensions?

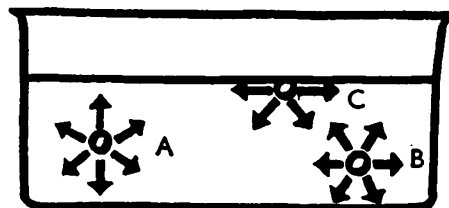


Fig. 63

### Simplified molecular picture of surface tension

Inside a liquid the molecules attract each other unless they are very very close together when they repel each other (as in collisions). As a result of the long range attractive forces a molecule such as A or B (Fig. 63) is, on the average, pulled equally in all directions. A molecule such as C on the surface will however have no liquid molecules above it to attract it. It will therefore on the average tend to be pulled downwards into the liquid. The results of such forces on all the surface molecules is that the surface tends to shrink whenever it gets the chance! This produces an effect which in some ways resembles the effects produced by a thin elastic skin. There is of course no actual skin on a clean liquid surface but the following experiments illustrate this effect.

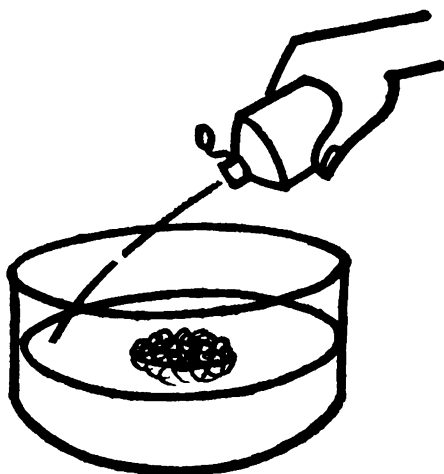


Fig. 64

**Experiment 5.24.**

(a) Float a needle, a razor blade, or a piece of steel wool on water (Fig. 64). Now drop in a little detergent. How does a detergent affect surface tension?

(b) Float some fragments of camphor on a clean water surface. Some parts of the camphor chips dissolve more quickly than others and

reduce the surface tension unevenly round the chip. Now add a little oil to the surface. Why do you think oil is sometimes poured 'on troubled water'?

(c) Pour as much water as possible into a tumbler. What do you notice about the shape of the surface?

An excellent film dealing with surface tension is available from Unilever House. It is called 'Outline of Detergency'.

**(4) Capillary attraction**

**Demonstration 5.25.** Select a few capillary tubes having different bores and stand them in a beaker containing coloured water. What do you observe? Repeat the experiment using mercury instead of water. Do your results suggest that the cohesive forces between water molecules are greater or less than the adhesive forces between water and glass molecules? Is the same true of mercury?

**Experiment 5.26.** Place a few small corks or pieces of balsa wood on a water surface. What happens when the pieces are close together? Why?

## Visual aids

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The following filmstrips contain material suitable for Chapters 5 and 6.

'The Atom' from Life Filmstrips.

'The Structure of Matter' from Common Ground.

The following excellent sound films are available from the Rank Film Library.

'What is Space?' 21/7483.

'Evidence for molecules and atoms' 21/7487.



# Atoms

## CHAPTER 6

### Molecules and atoms

Forests are made up of trees. Libraries are made up of books. Convoys are made up of ships. Matter, whether in the solid, liquid or gaseous state, is generally made of molecules. Just as the tree is the unit of a forest, the book the unit of a library and the ship the unit of a convoy, so the molecule is the unit of matter. It is the smallest part of a substance which still *is that substance*. Of course you can saw up trees, tear up books and break up ships, but if you do so you alter the nature of the forest, library or convoy. So too with the molecule. You can break it up but the bits with which you are left will be quite different from the original substance. For example if you take a molecule of water and break it up, you find that you are left, not with smaller bits of water, but with bits of two invisible gases, oxygen and hydrogen. Oxygen and hydrogen are two of the 92 elements found in nature.

The bits which go to make up the molecule are called atoms. The chemists say that an atom is the smallest part of an element which takes part in a chemical reaction. For example, in the above case two atoms of hydrogen com-

bine with one atom of oxygen to form a molecule of water (Fig. 65).

Atoms rarely go around alone. They prefer company. Hydrogen and oxygen atoms, for example, are normally found in pairs, so that a molecule of one of those gases is made up of two identical atoms (Fig. 66).

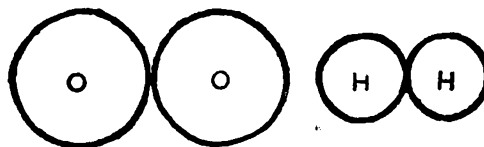


Fig. 66

### Arrangement of atoms

The way in which the atoms or molecules are arranged can make an amazing difference to the substance as we know it. The soot in a chimney and the diamond in a ring are both made of the same atoms (carbon) but you would hardly have guessed it. Another form of carbon is used for making pencils and for lubricating machines. It is called graphite. The carbon atoms in graphite are arranged in layers which slide easily on each other (Fig. 67 (a)). The atoms in diamond are held together much more rigidly, and so thoroughly are they bound together that diamond is one of the hardest substances known to man. Fig. 67 (b).

**Model 6.1.** Try to construct models showing the arrangement of atoms in graphite and diamond. You can represent the atoms by wood or plastic spheres or Plasticine. Matchsticks or cocktail sticks can be used to join them together.

**Experiment 6.2.** Use a razor blade or knife to cleave a piece of sodium nitrate or mica. (Mica may be obtained from an old electric-iron element.) Examine the slices you obtain.

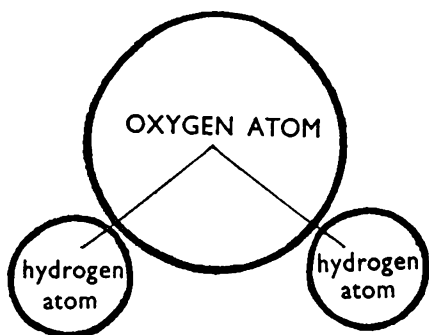
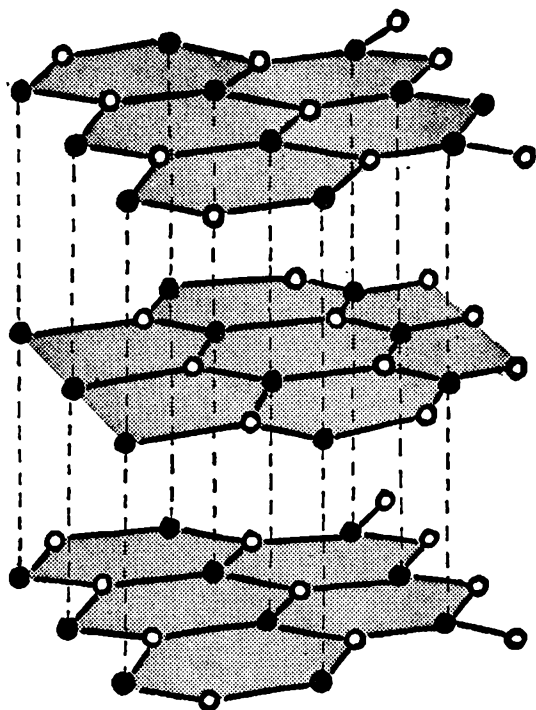
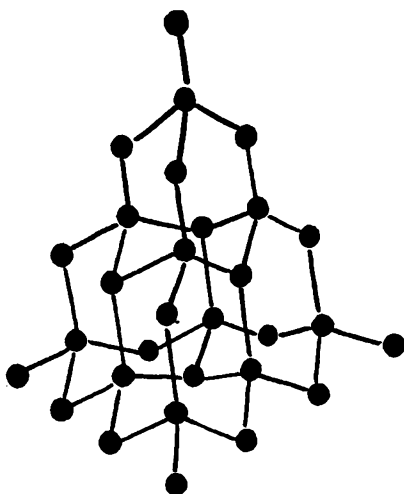


Fig. 65



GRAPHITE

Fig. 67(a)



DIAMOND

Fig. 67(b)

## What are atoms made of?

Although the Greeks suggested thousands of years ago that matter might be made of atoms,

it is only in the twentieth century that experiments have shown that the atom itself is not solid like a miniature billiard ball. It is actually made of even smaller particles. Before discussing these particles you should discover what electric charges do.

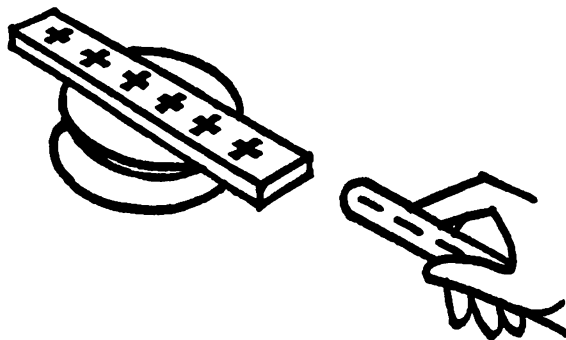


Fig. 68

### Experiment 6.3.

(a) For this experiment you will require two polythene strips, two cellulose acetate strips, two watch glasses, a cotton and a woollen cloth (Fig. 68). Rub one of the polythene strips with the woollen cloth and lay it on two watch glasses as shown. Rub the second polythene strip and bring it close to one end of the first strip.

(b) Repeat this experiment, using the two acetate strips rubbed with cotton.

(c) Now bring a rubbed polythene strip close to a cellulose acetate strip which has been rubbed and placed on the watch glasses.

(d) Can you find a third material which when rubbed will repel both polythene and acetate strips?

Report what you discover in each of the above experiments.

As only two types of charge have been discovered, they have been named positive (as, for example, on cellulose acetate or glass) and negative (as, for example, on polythene or ebonite). The names are merely labels and are not related to the mathematical use of those terms. Benjamin Franklin named the charge on glass 'positive' a hundred years before the tiny negatively charged particle (the electron) had

been discovered. As it is the electrons which move to or from a material when it is rubbed, many people think it would have been better if the names had been chosen differently. If you ever have the task of introducing the study of electricity to people on another planet you might consider doing this!

If a substance has more than its usual share of electrons it is said to be negatively charged. If it loses electrons it lacks negative charge and so is said to be positively charged. *Do positively charged rods attract each other? (1) Do negatively charged rods repel each other? (2) What effect does a positively charged body have on a negatively charged one? (3)*

### What you lose on the swings

In this experiment we will try to compare the size of the negative charge transferred and the positive charge left on a cellulose acetate strip.

**Demonstration 6.4.** This is a difficult experiment but it is so important that it is worth taking some extra care.

Make a simple gold-leaf electroscope, using a bottle, flask or Perspex food box. Cut two strips of light-weight silver paper and hook them on to a length of wire as shown in Fig. 69 (a). Alternatively flatten the end of the wire and glue on strips of Dutch metal or gold leaf as shown in Fig. 69 (b).

Now completely discharge a clean polythene rod and an acetate rod. This can be done by waving them in a bunsen flame. Test the rods with the electroscope to make sure they have been completely discharged. The leaves should not diverge.

Now put a small charge on the electroscope by stroking the electroscope hook or plate several times with a charged rod, so that the leaves diverge slightly and stay apart.

Rub the ends of the polythene and acetate rods together and touch the plate of the electroscope with the rubbed part of each rod in turn. What do you observe?

Finally, touch the electroscope plate with both rods at the same time. If the deflection of the leaf is unaltered when both charged rods touch the electroscope, what does this tell you about the charges on the two rods?

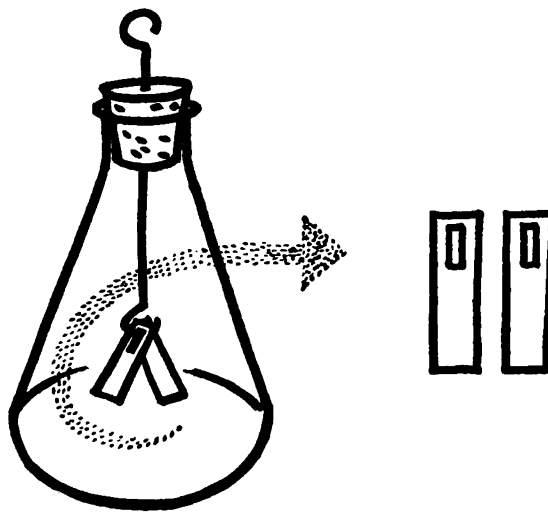


Fig. 69(a)



Fig. 69(b)

### Atomic models

There are models and models! Dinky toy cars are models. They give you some idea of what the real thing is like. No one would imagine, however, that if the toy were blown up to life size it would be a real car. A model of the atom is even less like the real thing. Like a parable, it is meant to teach one thing and not ten.

Three main types of particle are found in atoms. They are electrons (negatively charged), protons (each with a positive charge equal in size to the negative charge on the electron) and neutrons (neutral, that is, they have no charge). Practically all the mass of an atom is concentrated in its core or nucleus, which is made up of protons (+) and, usually, neutrons (0). These two nuclear particles are sometimes referred to as nucleons.

|                  |   |              |           |              |
|------------------|---|--------------|-----------|--------------|
| Hydrogen nucleus |   |              |           |              |
| 1 proton         |   | =            | 1 nucleon |              |
| Helium nucleus   |   |              |           |              |
| 2 protons        | + | 2 neutrons   | =         | 4 nucleons   |
| Lithium nucleus  |   |              |           |              |
| 3 protons        | + | 4 neutrons   | =         | 7 nucleons   |
| Oxygen nucleus   |   |              |           |              |
| 8 protons        | + | 8 neutrons   | =         | 16 nucleons  |
| Uranium nucleus  |   |              |           |              |
| 92 protons       | + | 146 neutrons | =         | 238 nucleons |

To give you some idea of how heavy these nucleons are it has been estimated that one cubic centimetre filled with nucleons alone would weigh 250 million tons.

### Electrons in orbit

About fifty years ago Lord Rutherford suggested that the positively charged nucleus of an atom has negatively charged electrons spinning round it and attracted to it. This theory was later modified by Niels Bohr. The atom was pictured as being like a miniature solar system with the nucleus as the sun and the electrons circling around it in much the same way as the planets orbit the sun. This model reminds us that most of the atom is in fact empty space (Fig. 70).

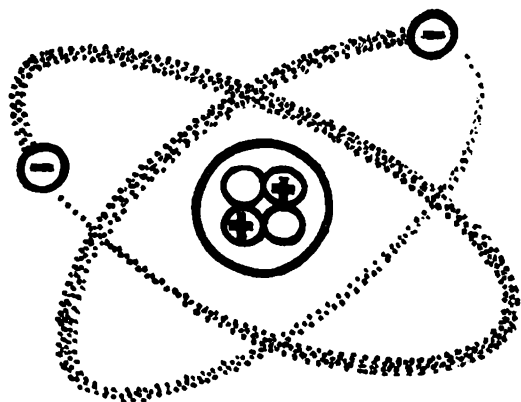


Fig. 70

*As an atom is electrically neutral how would you expect the number of orbital electrons to compare with the number of protons in the nucleus? (4)*

Later theories suggested that, as the electrons whirl round the nucleus thousands of millions of times every second, and as the orbits are changing position rapidly all the while, it might be better to think of 'electron shells' round the nucleus. The blades of an electric fan seem to weave a transparent 'disc'. A single fast-moving spot of light on a television screen gives the impression of a complete picture. The shell model of the atom pictures it as a kind of microscopic onion with layer upon layer of electron shells. In other models of the atom the shells have changed to clouds or puffs of smoke round the nucleus (Fig. 71). Somewhere in one of those clouds you may find an electron!

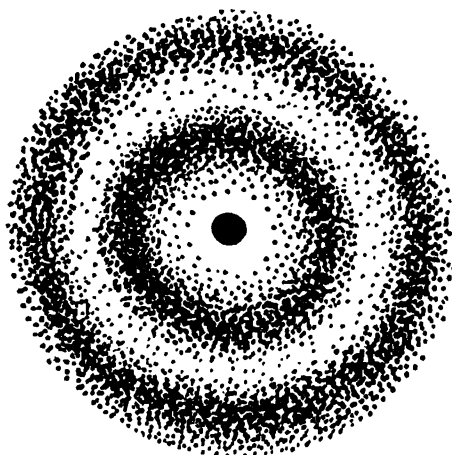


Fig. 71

Modern theories of the atom regard the electron as behaving both as a particle and as a wave. Physicists find it more helpful to regard it sometimes as a particle and at other times as having a wave nature. Its behaviour as a wave is best described by advanced mathematics.

### Particles

Electrons, protons and neutrons are the most important atomic particles, but a large number of others have been and are being discovered. In fact there are now about as many particles as there are elements. Many of these particles exist only for a small fraction of a second before changing into other forms. Are those particles really the smallest things that can exist or can

they in turn be split up? This is the 64,000-dollar question. At present we know very little about the nature of those so-called fundamental or elementary particles, although it has been suggested that they themselves may turn out to be complex.

## Summary

- All substances (gases, liquids and solids) are made of molecules.
- All molecules are made up of one or more atoms.
- All atoms are made up of electrons (—), protons (+) and in most cases neutrons (0).

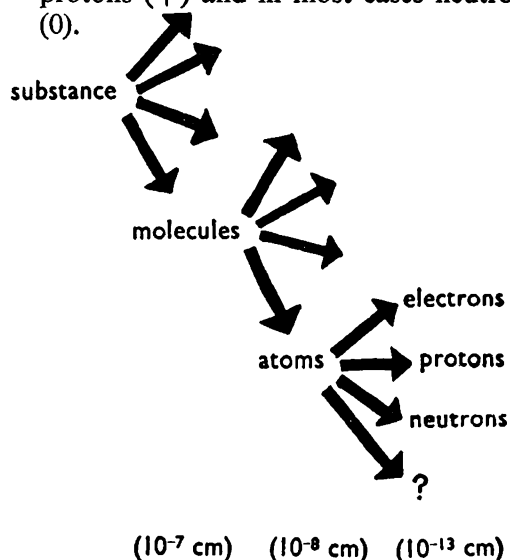


Fig. 72

Just as twenty-six letters make up thousands of words and those words make up millions of books, so a few particles make up 92 atoms, and those 92 atoms make up all the thousands of substances in nature.

## Thirteen steps

The following illustrations help us to picture atomic dimensions.

(a) If a thimbleful of air were enlarged to the size of the Earth the molecules would then be the size of tennis balls and would be ten feet apart on the average.

(b) If the whole Earth, both land and sea, were covered with sand to a depth of six inches

there would be about the same number of grains of sand as there are atoms in a pint of water.

In a brilliant collection of photographs called *The Thirteen Steps to the Atom* the author, C. N. Martin, uses as his steps DIVISION BY TEN. If we take 1 cm as the starting point the first step is  $\frac{1}{10}$  cm ( $10^{-1}$  cm), the second  $\frac{1}{10}$  of  $\frac{1}{10}$  cm, that is  $\frac{1}{100}$  cm ( $10^{-2}$  cm), the third  $\frac{1}{1000}$  cm ( $10^{-3}$  cm), the fourth  $\frac{1}{10000}$  cm ( $10^{-4}$  cm), and so on. By the time we reach the seventh step ( $10^{-7}$  cm) we are approaching the size of molecules. At the eighth step ( $10^{-8}$  cm) we reach the size of atoms and by the thirteenth step ( $10^{-13}$  cm) we have reached the size of the sub-atomic particles.

Ordinary optical microscopes cannot be used much beyond the fourth step. Electron microscopes, using beams of electrons instead of light rays, can give us greater magnification. The field-ion microscope produces an even greater magnification of several million. Of the small atomic particles no microscope has yet been able to produce pictures, but photographs have been taken of the paths along which they move. A jet plane leaves a vapour trail which can often be seen even if the plane is invisible. A charged particle such as an electron can leave a trail or track in a cloud chamber or bubble chamber. Sub-atomic particles can also be detected by the tracks they leave in photographic emulsions.

## Ions

Under normal circumstances an atom is electrically neutral. The number of negatively charged electrons is exactly equal to the number of positively charged protons in the nucleus. If

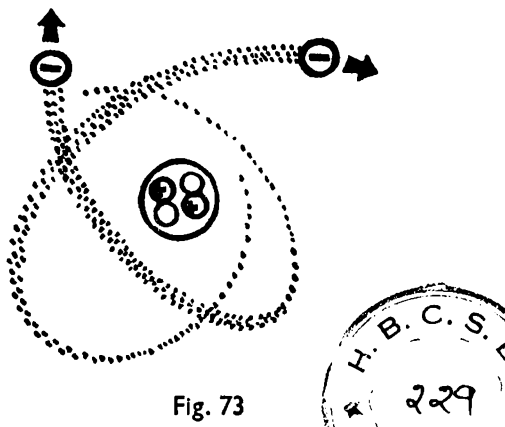


Fig. 73

an atom loses one or more electrons it is left with a positive charge and is referred to as a positive ion. If an atom gains an electron it is called a negative ion. Groups of atoms which are electrically charged are also called ions.

If a helium atom loses its electrons the nucleus becomes a positive ion (Fig. 73). It is called an alpha particle. *Name the nucleons in an alpha particle.* (5)

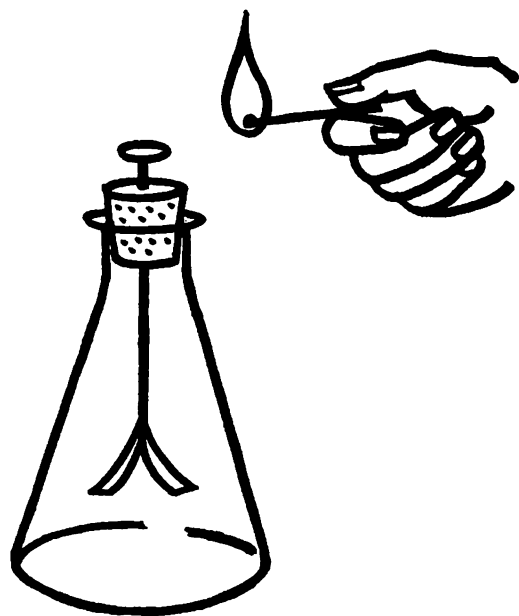


Fig. 74

**Experiment 6.5.** Charge an electroscope so that the leaves diverge and stay apart. Now light a match and bring it close to the top of the electroscope (Fig. 74). What happens to the leaves?

When the air molecules are heated by the match some of them become so excited that they split up into two charged fragments (ions). Some of those ions are attracted to the gold-leaf electroscope and neutralise the charge on it.

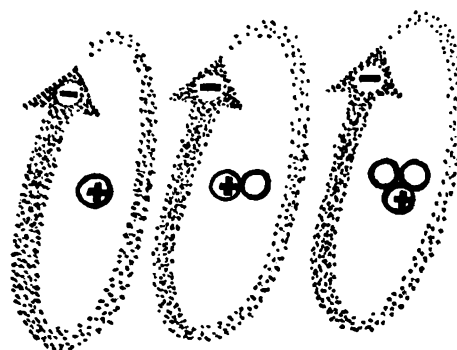
To sum up, atomic fragments or groups of atoms which are electrically charged, either positively or negatively, are called ions.

## Isotopes

The nucleus of an atom has the same number of protons as there are electrons spinning round

it. In addition all nuclei except ordinary hydrogen contain neutrons. *What kind of electric charge do neutrons have?* (6) *What kind of charge does the atom have as a whole?* (7)

A given element will always have a particular number of electrons spinning round the nuclei



Hydrogen      Deuterium      Tritium

Fig. 75

of its atoms, but the number of neutrons in each nucleus need not necessarily be the same. If the number of neutrons is *not* the same the element is said to have *isotopes*. The 'outsides' of the atoms are the same although their 'insides' are different. Most of the elements have naturally occurring isotopes. Hydrogen, for example, has three isotopes: (i) ordinary hydrogen, with one proton as its nucleus; (ii) heavy hydrogen (deuterium), with one proton and one neutron in its nucleus; and (iii) tritium, with one proton and two neutrons in its nucleus (Fig. 75). All three atoms, however, have each only one electron circling the nucleus, and all three show similar properties. For example, you would not be able to tell the difference when washing in water made up of hydrogen and oxygen, deuterium and oxygen or tritium and oxygen. Deuterium and tritium are very rare compared with ordinary hydrogen.

Sea-water contains some deuterium. When atoms of deuterium and tritium are fused together large quantities of energy can be released as in the hydrogen bomb. Unfortunately, we do not yet know how to control this fusion process. We do know that three cupfuls of sea-water contain enough deuterium to produce as much heat as a bag of coal, but do

not yet know any simple way of usefully releasing this energy supply.

## Radio-activity

The alchemists used to dream of changing cheap metals into gold. After many years of fruitless experiment the attempt was given up, and scientists thought that it was impossible ever to change one metal into another.

In 1896 a Frenchman called Henri Becquerel discovered a dark spot on an unexposed photographic plate that had been kept in black paper before being developed. Some uranium ore had been lying on the parcel of photographic paper. The spot was just below the uranium. This led Becquerel to study uranium more closely, and he found that certain rays were coming from it. We now know that the uranium atoms were exploding one by one, and sending out rays. As they did this, the uranium was itself changing into another kind of material. This process is called RADIO-ACTIVITY. The rays given off affect photographic plates and fluorescent materials.

**Demonstration 6.6.** Take a piece of high-speed photographic film, such as Agfa Isopan Record, and wrap it in a single sheet of thin black paper. Place a small metal object, such as a washer, on top of the packet. Cover the washer with a radio-active source such as uranyl nitrate or uranium oxide. A Halford's 'Keylight' or a gas mantle may also be used. Leave the

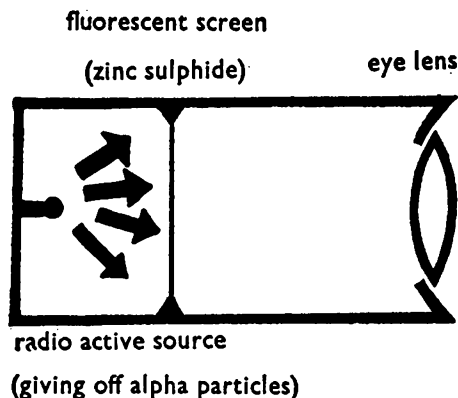


Fig. 76

apparatus for 12 hours or more before developing the film. Report on what you see.

Today a worker who is likely to be exposed to dangerous radiations wears a special badge. Inside the badge, protected from light, is a piece of sensitive photographic film which records the amount of radiation striking it.

**Experiment 6.7.** You can observe the effects of radio-active explosions by looking into a spinthariscopes (Fig. 76). Here the tiny fragments which are being shot out from the source strike a fluorescent screen. A small flash of light is seen every time a particle strikes the screen. You will have to stay in a completely dark room for about ten minutes for your eyes to become adapted. Otherwise you will not be able to detect these tiny flashes.

A similar effect may be observed by examining fluorescent paint through a powerful lens.

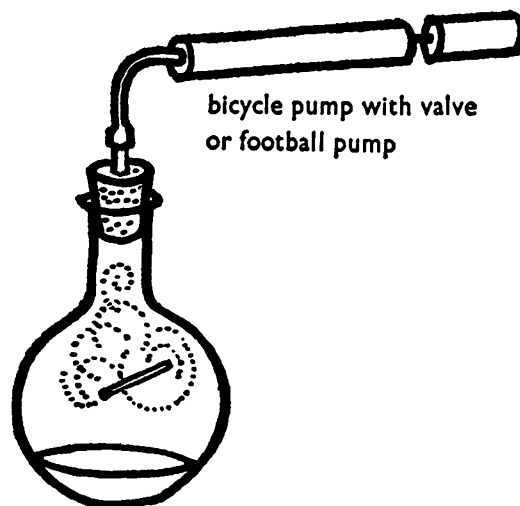


Fig. 77

**Demonstration 6.8.: Making clouds.** Put a little water into a strong flask or milk bottle. Now drop in a lit match, thus allowing some smoke particles to enter the flask. Pump air into the flask using a football or bicycle pump and valve (Fig. 77). About half a dozen strokes should be sufficient. Is there any cloud visible in the flask? Wait a few moments to allow the air in the flask to cool down, and then release the pressure in the bottle quickly by pulling off the rubber tubing. The expanding air cools

down still further and water vapour condenses on the smoke particles, thus forming clouds. Clouds can form on dust particles or on electrically charged particles when the pressure is reduced.

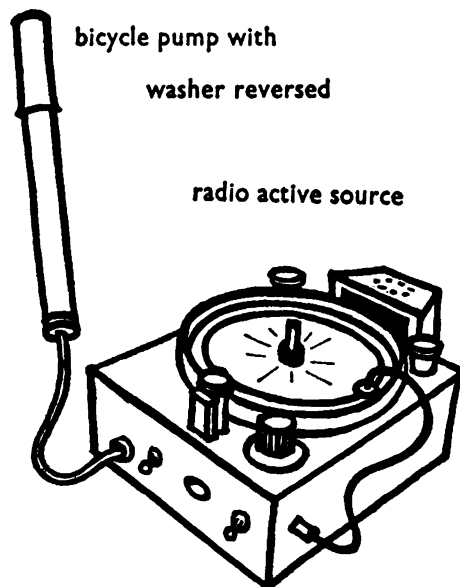


Fig. 78

**Demonstration 6.9: Cloud chamber.** Perhaps the most fascinating device for detecting the particles which shoot out from a radio-active explosion is the cloud chamber (Fig. 78). This was invented by C. T. R. Wilson in the early part of the twentieth century, and enabled scientists for the first time to follow the paths of these particles. It has contributed greatly to the progress of atomic research up to the present day. You should study the paths of alpha particles (nuclei of helium atoms) as they shoot out from a radio-active source. What are the component parts of an alpha particle? (W. B. Nicolson and Leybold produce excellent cloud chambers for school use.)

**Demonstration 6.10: Geiger counter.** One of the most useful instruments for detecting radio-active particles is the Geiger counter (Fig. 79). Suitable ratemeters are available for schools from Panax and Philip Harris. Such instruments enable you to hear a click in a loud-speaker every time a particle enters a Geiger tube. They also provide a meter indication of

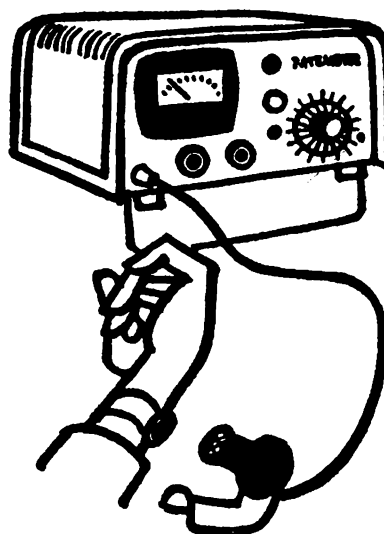


Fig. 79

the number of particles arriving each second. You should see demonstrated the effect of putting lead and other substances in the paths of those particles.

## Radiation

When radio-active substances disintegrate (explode) various particles or rays shoot out. They are called by the first three letters of the Greek alphabet. Alpha particles are the nuclei of helium atoms, that is, ionised helium atoms. Beta particles are fast-moving electrons and gamma rays are in some ways similar to radio waves, light waves and X-rays, but are much more penetrating and energetic. In addition they have a very much shorter wave-length, of the order of a millionth of a millionth of a metre.

Radio-active substances can be produced artificially by bombarding non-radio-active elements with suitable bullets (alpha particles). This was first done by the Joliot-Curies in 1934 when they bombarded aluminium and produced radio-active silicon.

Radiation from radio-active sources can be very dangerous and atomic scientists take elaborate precautions to avoid exposure to it. Atomic explosions cause these deadly



rays to be radiated for miles in all directions and produce large quantities of radio-active dust. This dust is the radio-active fall-out which can be carried for thousands of miles round the Earth.

If uranium is left long enough it will change into radium and then eventually into lead. Scientists have been able to estimate the age of the Earth by finding the rate at which those changes take place and determining the amount of uranium, radium and lead present in a sample of natural uranium. They estimate by this method that the Earth is about four and a half thousand million years old.

### Rays in space

Listen to a Geiger counter which has no radio-active source near it. Apparently some particles are entering the Geiger tube all the time.

Scientists refer to this as background radiation. *Are particles reaching the Geiger tube at regular intervals? (8) How are they arriving? (9)*

Experiments using balloons and satellites have shown that this radiation increases rapidly as the instruments rise through and above the Earth's atmosphere. The nature of this 'cosmic radiation' was a mystery for many years, but one culprit has now been discovered. Cosmic rays have been found to consist mainly of high-speed protons. Some of them are moving very close to the speed of light, 186,000 miles per second. In their investigations of cosmic rays scientists also discovered many of the short-lived elementary particles, many of which have been artificially reproduced in some of the world's large particle-accelerators. It is by the study of these particles that nuclear scientists hope to solve some of the mysteries of the atomic nucleus.

### Visual aids

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The following charts may be found helpful for this section. They are obtainable from the Central Electricity Generating Board.

*Famous Scientists*, Nos. 17, 18, 19, 20 and 21.

The P.S.S.C. film 'Crystals' is particularly suited to this section of the course. It is available from the Scottish Central Film Library.

'Atomic Energy inside the Atom' (21/7452) is also relevant. It may be borrowed from the Rank Film Library.

# Measuring matter

## CHAPTER 7

### Measure: Weigh: Strain: Heat

Matter exists in three states: solids, liquids and gases. You will be asked to observe carefully the results you obtain as you (1) measure, (2) weigh, (3) strain and (4) heat matter in each of these three states.

### Measuring solids—length, area and volume

The first measurement we have to take is that of length. Before we can measure length we require some standard or unit of length. The Indians used the *pace* or *bowshot* or *day's journey* as units. The ancient Egyptians made their great stone buildings using the cubit as their unit of length. It is the distance from the elbow to the tip of the middle finger. *How long was Noah's Ark? (1)*



Fig. 80

King Henry I decided that the yard should be defined as the distance from the point of his nose to the end of his thumb (Fig. 80).

King David I of Scotland ordained that the inch be the average width of the thumbs of three Scotsmen—one tall, one medium and one short. The measurement had to be taken at the root of the nail. In the reign of King Edward II an inch was the length of three barleycorns laid end to end. *Why are these units not considered suitable today? (2)*

Only 200 years ago about 200 different lengths were each called a *foot*. After the French Revolution a group of experts set to work to produce a new set of units. They looked for a length which was constant, and decided to take the distance from the Equator to the North Pole through Paris. As this is rather too large for most practical purposes they took one ten-millionth ( $10^{-7}$ ) of it as their unit of length. This length is called the *metre* and is used by practically all scientists today.

In practice a metal bar is used as the standard of length. It is made of platinum iridium, rests on two rollers and is kept at a constant temperature. *Why is it kept at constant temperature? (3)* It is called the International Prototype Metre and is kept near Paris. Copies of this bar are used in other countries. They are called *sub-standards*. A similar standard is used for the British system of units. It is a bronze bar resting on eight rollers and called the Imperial Standard Yard. It is kept at the Board of Trade offices in London.

It has been found recently, however, that the length of a metal bar, or the distance between two marks on a metal bar, does not give a sufficient degree of accuracy for some specialised jobs. Since 1960 therefore the metre has been defined in a quite different way. It is now said to be a certain number of times (1,650,763.73 in fact!) longer than the wave-length of the orange radiation from a Krypton discharge lamp.

In the French system (*metric system*) multiples of 10, 100, 1,000, and so on, are used.

1 micron ( $\mu$ ) =  $\frac{1}{1000000}$  part of a metre ( $10^{-6}$  m). It is about the thickness of a soap bubble film.

1 millimetre (mm) =  $\frac{1}{1000}$  part of a metre ( $10^{-3}$  m). This is about the thickness of a pencil lead.

1 centimetre (cm) =  $\frac{1}{100}$  part of a metre ( $10^{-2}$  m). This is slightly less than half an inch; in fact  $2.54 \text{ cm} = 1 \text{ in.}$

1 metre is over a yard long ( $39.37 \text{ in.}$ ).

1 kilometre (km) = 1,000 metres ( $10^3 \text{ m.}$ ). It is about five-eighths of a mile ( $0.62 \text{ mile.}$ ).

There is no need to remember all those conversion numbers, but you should know that  $1 \text{ inch} = 2.54 \text{ cm.}$  *How would you test that this is correct?* (4)

Having found the length of each side of a rectangular solid it is an easy matter to find the area of its faces. *How would you find the area of a rectangle?* (5)

The next measurement of a solid which we have to make is its volume. You can find the volume of a rectangular box by multiplying the length by the breadth by the height. *If those lengths were expressed in centimetres, in what units would the area of each face and the volume of the box be given?* (6) *What would you obtain by multiplying the area of the base by the height?* (7)

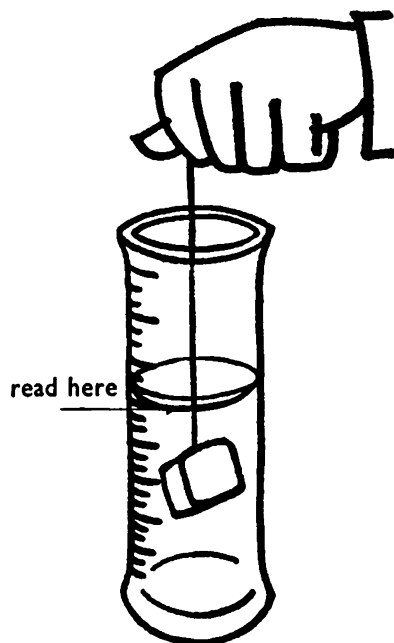
*A rectangular brick is 25 cm long, 8 cm wide and 4 cm high. Calculate the areas of all its faces and the volume of the brick.* (8) *If you were to measure such a brick with a ruler would you give each length to the nearest metre, centimetre, millimetre or tenth of a millimetre?* (9)

**Experiment 7.1.** Measure several rectangular blocks and calculate their volumes.

### Irregular solids

An object such as a brick or a cylinder is called a regular solid. By taking various measurements of length the volume of such a

solid can be calculated. Most solids have peculiar shapes however. They are said to be irregular solids. A stone, a shoe, a bicycle, and you, are irregular solids. The volumes of such solids cannot be calculated easily from a few measurements of length.



meniscus with water

Fig. 81

**Experiment 7.2.** Half fill a measuring jar with water and read the volume. The curved surface is called a meniscus. You should take the reading opposite the bottom of this meniscus (Fig. 81). Lower a stone or other irregular solid into the jar and take the new reading of volume. From this reading calculate the volume of the solid.

*What does the meniscus on top of mercury look like?* (10) *Draw a sketch showing mercury in a small measuring jar and indicate where you would read the scale.* (11)

For larger objects a displacement can may be used. A large fruit tin with a spout soldered on to it would be suitable (Fig. 82). *Describe how you would use such a can to find the volume of a solid object which is small enough to fit inside it.* (12) *How do you think you might be able to find*

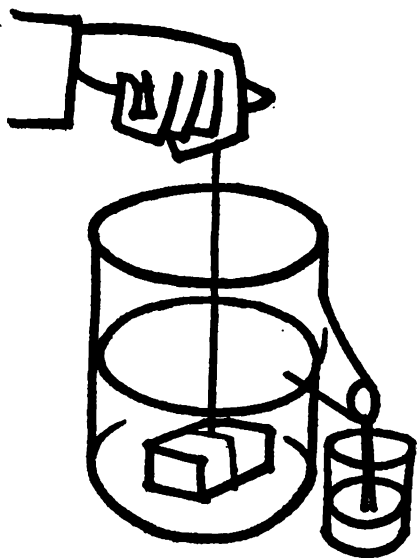


Fig. 82

*the volume of a shoe, a bicycle, and yourself? (13) How would you find the volume of an irregular lump of sugar? (14) Can you suggest a method of finding the volume of an irregular piece of cork which floats on water? (15)*

### Eureka!

Over 2,000 years ago a scientific detective was faced with a problem. He was asked to find the volume of a crown which King Hero of Syracuse had decided to present to the Temple of the Gods. The king suspected that his goldsmith had not used all the gold he had been given to make the crown and had replaced some of it with silver.

The scientific detective, whose name was Archimedes, found that the crown weighed the same as the gold, but he wasn't sure if it had the same volume. How could he find the volume of such a beautiful crown without destroying it?

He was thinking about the problem as he stepped into his bath one day. Suddenly he realised that just as water overflowed when he stepped into the bath, so he could cause water to overflow by placing the crown in water, and in this way he could measure the volume of the crown.

Archimedes was so excited by the thought of this discovery that he is reputed to have jumped out of his bath and run naked through

the streets shouting, 'Eureka, Eureka!' meaning 'I have found it!' He also found that the goldsmith had replaced some of the gold by silver, but the records leave the punishment to the imagination of the readers.

Displacement cans are still often referred to as 'Eureka' cans in memory of Archimedes' historic shouts of glee.

## Liquids

'And the gathering together of the waters called he Seas'—Genesis 1:10.

Seventy per cent of the Earth's surface is covered by water to an average depth of two and a half miles. The average depth of the seas is five times greater than the average height of the land above sea level. *How did this tremendous volume of water form on the Earth? (16)*

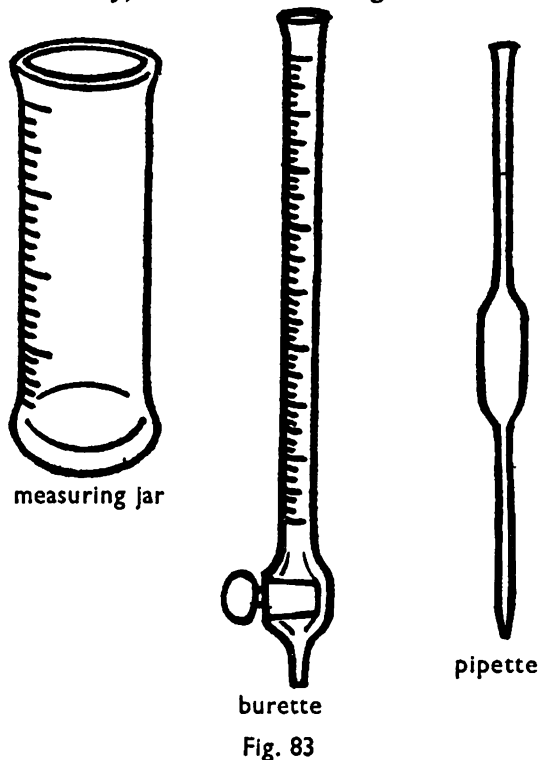
The Earth probably began as a ball of flaming gas. As it cooled down it would pass through a liquid state, during which time the denser materials would move towards the centre and the less dense towards the outer crust. With further cooling the surface solidified. As the temperature at which rocks solidify is well above the boiling point of water, any water present would be in the form of a thick steamy vapour surrounding the planet. The heavy vapour clouds surrounding the Earth would prevent the sun's rays from reaching it and gradually the Earth cooled down enough to cause some of the water vapour in the atmosphere to condense. The first rain would then fall. At first the hot Earth would cause the rain-water to evaporate when it landed, but gradually over the centuries the Earth would cool and allow seas to form.

Today the oceans are the Earth's greatest storehouse of minerals. Practically every known element is to be found there. Nearly two hundred million tons of dissolved salts are present in one cubic mile of sea-water. Food, raw materials and energy for the world of tomorrow may be obtained in ever-increasing quantities from the sea around us.

## Measuring liquids

A liquid differs from a solid in that it takes up the shape of its container. You cannot there-

fore measure the length and breadth of a liquid, although of course you could measure the surface area and depth of a liquid in a vessel. A more important liquid measurement is its volume. The simplest way to find the volume of a liquid is to pour it into a calibrated jar. Three such containers, which you should use in the laboratory, are illustrated in Fig. 83.



Liquid volumes are often measured in litres. One litre is the volume of one thousand grams of pure water at  $4^{\circ}\text{C}$ . A thousandth part of a litre (1 millilitre or ml) is, for most practical purposes, equal to  $1\text{ cm}^3$ .

### Measuring gases

Solids are usually sold by weight. We buy a pound of sugar, a hundredweight of coal. Liquids, on the other hand, are usually sold by volume. Milk is measured in pints and petrol in gallons. *Can you suggest a reason for this difference?* (17) It would, of course, be possible to sell solids by volume also and this is sometimes done, as in the case of wood.

Volume variations in solids and liquids due

to temperature and pressure differences are so small that the retailer would not normally worry about them. A gas, however, may have almost any volume at all. Put your finger over the end



Fig. 84

of a bicycle pump and push the plunger in (Fig. 84). You can reduce the volume of the air inside to half its original volume or less by increasing the pressure.

*Will there be more (that is a greater mass of) coal gas in a cubic foot at high pressure or at low pressure?* (18)

The molecules of solids and liquids have a great attraction for each other. Although they are always moving they are held together by strong forces. Gas molecules on the other hand are practically free to move around as they please. Under normal conditions gas molecules are sufficiently far apart for the forces of attraction between them to have little effect.

If all the air were pumped out of a room and then one cubic centimetre of air were again introduced into the room, that small volume of air would expand until it filled the whole room. Of course the pressure and mass of air would be small and the molecules would be much farther apart than they are normally. If now another cubic centimetre of air were allowed into the room the two cubic centimetres would completely fill the room. The pressure and mass of air present would, however, have been doubled. Scientists have discovered the amazing fact that if the room were filled with gas at a

certain pressure and temperature there would always be exactly the same number of molecules in the room, no matter which gas was present.

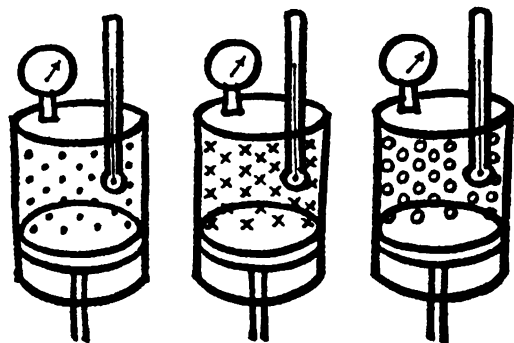


Fig. 85

The mass of gas in the room would, of course, be different for each gas because the molecules of some gases, such as hydrogen, are light and the molecules of others, such as chlorine, are heavy.

Suppose that three different gases are contained in three identical cylinders as shown in Fig. 85. As the volume, pressure and temperature are the same in each cylinder there will be the same number of molecules in each.

A gas will always completely fill its container, so that you can measure the volume of the gas only if you know the volume of the vessel in which it is enclosed. For this reason we will normally use a graduated glass container to hold a gas whose volume we want to find.

# Weighing matter

## CHAPTER 8

### Weight and mass

If your mother sent you for some potatoes the grocer would find it rather difficult to measure the volume of the potatoes. It could, of course, be done, but it would be laborious. A coalman wouldn't thank you for asking him to drop each piece of coal into a measuring jar or displacement can and thus find the volume of the coal you were buying. How then can we measure quantities of potatoes and coal?

If we could count all the molecules or atoms we might ask for a certain number of molecules of coal. This again would be completely impracticable. Fortunately there is a simple answer to this problem.

The Earth pulls downwards on a body. We call this gravitational pull the *weight* of the body. When a body is suspended by a spring the spring is stretched and we can use this stretch to indicate the pull of the Earth on the body.

Gravity is very obliging. It exerts almost the same pull on a given body everywhere on the Earth's surface. It is true that this force is slightly less on high hills, but the difference need not worry us just now. If you were a spaceman, however, things would be different. You could not use a spring balance to weigh out a pound of sugar in a space capsule. The sugar would be 'weightless'. *Does this mean that there is less sugar? (1)* If we measured the volume or counted its molecules, we would find that there was just the same quantity as there was on Earth. This 'something' which remains the same on the Earth, on the moon or in outer space scientists refer to as *mass*. As we are likely to do most of our experiments on Earth we will measure the mass of a body by weighing it. A body with twice the mass will have twice the weight, one with thrice the mass will have three times the weight and so on. Later you will do

experiments in which you measure mass by other methods.

A chunk of metal which has a mass of one pound (1 lb) is kept in London and a standard mass of one kilogram (1 kg) is kept near Paris. We use copies of them in the laboratory. They are usually referred to as 'weights' although masses would be a better name. We will not worry too much about this distinction just now, but we will normally use the term *mass* unless we are thinking of the force which the Earth exerts on a substance, in which case we will use *weight* or *gravitational attraction*. We will weigh a substance in order to find its mass.

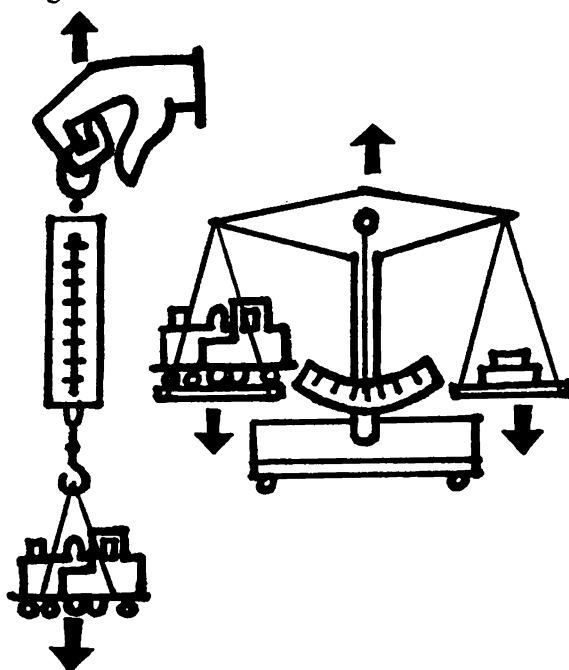


Fig. 86. Finding, left, the gravitational mass or weight of the engine and, right, finding its mass by comparing it with standard masses ('weights')

### Weighing solids

A spring balance measures the pull of the Earth

and therefore could be used to find the weight of a toy engine (Fig. 86). A chemical balance uses the Earth's pull to compare the weight of the engine with the weight of a known body (a brass 'weight'). If the balance were taken to the moon, where gravitational pull is about a sixth of that on the Earth, the engine would be balanced by the same 'weights' or masses. A balance of this kind is really comparing the Earth's pull on the engine with the Earth's pull on a known mass, and therefore we can find the mass of the engine, since if two bodies have the same weight at the Earth's surface (or the moon's) they have the same mass.

Balances were probably used by the Egyptians 7,000 years ago. Remains found in Egyptian tombs suggest that ancient balances and weights were made of limestone. *Name some of the places in which you might expect to find balances being used today.* (2)

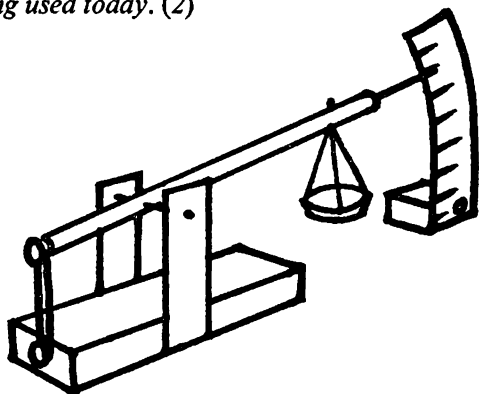


Fig. 87

### Experiment 8.1.

(a) Here is a simple balance you can build from such things as a piece of  $\frac{1}{4}$ -in dowelling, an elastic band and a milk bottle top (Fig. 87). Calibrate the balance to read from 0–12 gm using known masses ('weights').

(b) You can now use the balance to find the masses of 1-cc cubes of wood and different metals.

(c) Construct a 1-cc cubical box from centimetre graph paper, wax it and use it to find the mass of 1 cc of water.

**Experiment 8.2.** A more sensitive balance can be built to weigh very small objects. The beam consists of a drinking straw cut at one

end to form a cup to hold the object being weighed (Fig. 88). Into the other end is fitted

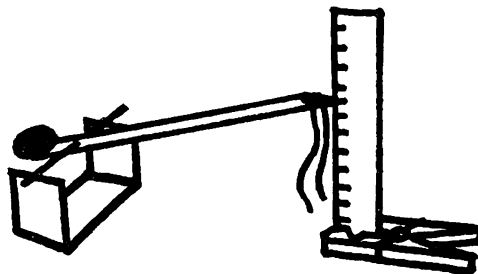


Fig. 88

a small piece of Plasticine and/or a nail or bolt. A needle is pushed through the straw about an inch from the end and rests on the upper edges of a U-shaped strip of tin plate. Should the needle be pushed through the widest part of the straw? If not where should it be inserted and why? A card glued to a small block of wood or held by a clothes peg may be used for the scale. Can you think of a way to mark a numbered scale (calibration) on this balance by cutting up sheets of graph paper and using the pieces as 'weights'? Report on the mass of any object you measure with this balance.

### Units

We will use the units now recommended by the British Standards Institution. Mass is measured in grams (g) in the metric system and in pounds (lb) in the British system of units.

The force exerted by gravity (taken as constant) on a mass of one gram (1 g) is called *one gram force* (1 gf). The old name was one gram weight (1 gm wt). A spring balance is therefore calibrated (marked) so that when a mass of 1 g is attached to it the pointer reads 1 gf. Similarly a mass of 1 lb will weigh *one pound force* (1 lbf). The old name for this force was one pound weight (1 lb wt).

Just as you will use metres more often than yards in scientific work so you will use grams more often than pounds. An electron has a mass of the order of  $10^{-27}$  g, a tiny pencil mark on paper  $10^{-6}$  g, a postage stamp  $10^{-2}$  g, a house  $10^8$  g and the sun  $10^{33}$  g.



## Density

We say that iron is heavier than wood, yet a tree is heavier than a poker. Is mercury heavier than water? The question has no answer as it depends on how much mercury and water you are comparing. Most people understand that the same amounts of each are being compared. *Why is 'amount' not a good word to use in the last sentence?* (3) We should really say that we are comparing equal *volumes*. The original question then should read, 'Is mercury heavier than an equal volume of water?'

We could simplify the question if we could find a word which indicated 'mass of, let's say, one cubic centimetre'. There is such a word. It is *density*. In the metric system density means the mass of 1 cm<sup>3</sup>. Our third attempt, therefore, at the question could be, 'Is mercury denser than water?' There is now no doubt as to the meaning of the question.

If a 10-cm<sup>3</sup> iron block has a mass of 75 g, then 1 cm<sup>3</sup> must weigh 7.5 g. We say the density of iron is 7.5 grams per cubic centimetre (7.5 g/cm<sup>3</sup>).

Thus density =  $\frac{75}{10}$ , that is density =  $\frac{\text{mass}}{\text{volume}}$ .

10 cm<sup>3</sup> of gold have a mass of 193 g. What is the mass of 1 cm<sup>3</sup> of gold? (4) What is the density of gold? (5)

120 cm<sup>3</sup> of glass have a mass of 300 g. Find the mass of 1 cm<sup>3</sup> and the density of glass. (6)

The density of balsa wood is 0.2 g/cm<sup>3</sup>. What is the mass of (a) 1 cm<sup>3</sup>, (b) 10 cm<sup>3</sup>, (c) 50 cm<sup>3</sup> of balsa wood? (7)

Iron has a density of 7.5 g/cm<sup>3</sup>. What is the mass of (a) 1 cm<sup>3</sup>, (b) 10 cm<sup>3</sup>, (c) 100 cm<sup>3</sup> of iron? (8)

1 g of water has a volume of 1 cm<sup>3</sup>. What is the volume of (a) 10 g, (b) 55 g of water? (9)

The density of iron is 7.5 g/cm<sup>3</sup>. Find the volume of (a) 15 g, (b) 75 g of iron. (10)

If we use *D* for density, *m* for mass and *V* for volume we can express them as:

$$D = \frac{m}{V}$$

$m = D \times V$ 
 $V = \frac{m}{D}$

In the British system of units we can think of density as mass per cubic inch or cubic foot. For example water has a density of 1 g/cm<sup>3</sup> which, in British units, means that its density is 62½ pounds per cubic foot (62½ lb/cu ft).

**Experiment 8.3.** Measure the sides of a rectangular block and calculate its volume. Find the mass of the block on a Butchart balance and hence determine the density of the material. Repeat this with blocks of different materials. Make a table of results showing the densities of the different solids.

Philip Harris and Serinco will supply suitable blocks 5 cm × 5 cm × 4 cm.

*A metal block measures 4 cm × 6 cm × 5 cm and has a mass of 960 g. What is the density?* (11)

*The density of a cork is 0.25 g/cm<sup>3</sup>. Find the mass of 100 cm<sup>3</sup> of cork.* (12)

*Find the volume of a piece of wood of mass 50 g and density 0.5 g/cm<sup>3</sup>.* (13)

*Which has the greater mass, 40 g of cork or 15 g of wood, if their densities are as stated above?* (14)

*A 2-cm cube of aluminium has a mass of 21.6 g. A gold cube of the same size would have a mass of 154.4 g. Find the densities of these two metals.* (15) *Approximately how many times is gold as dense as aluminium?* (16)

## Weighing liquids

It may be possible to weigh a liquid by pouring it into a balance pan. You will find, however, that this procedure will not be appreciated by your teacher. *Give three reasons why this is not a recommended way of weighing liquids.* (17)

To find the mass of a liquid, first find the mass of an empty container such as a beaker and then find the mass of the beaker with the liquid in it. By subtracting the mass of the beaker from the mass of the beaker plus liquid, the liquid mass may be calculated. If a measured volume of liquid is poured into the container and the mass found, you can then calculate the density of the liquid.

**Experiment 8.4.** Use the above method to find the density of water, methylated spirit, oil, carbon tetrachloride or any other liquids.

Make a list of the liquid densities you have measured.

*Here are some typical results. Copy them into your notebook and fill in the blanks. (18)*

|                      |                              |
|----------------------|------------------------------|
| Mass of can          | = 100 g                      |
| Mass of can + liquid | = 130 g                      |
| Mass of liquid (m)   | = g                          |
| Volume of liquid (V) | = 40 cm <sup>3</sup> (or ml) |

|                                 |                     |
|---------------------------------|---------------------|
| Density of liquid $\frac{m}{V}$ | = g/cm <sup>3</sup> |
|---------------------------------|---------------------|

|                         |                       |
|-------------------------|-----------------------|
| Mass of beaker          | = 200 g               |
| Mass of beaker + liquid | = 265 g               |
| Mass of liquid          | = g                   |
| Volume of liquid        | = 100 cm <sup>3</sup> |
| Density of liquid       | = g/cm <sup>3</sup>   |

|                                          |                      |
|------------------------------------------|----------------------|
| Mass of container                        | = 250 g              |
| Mass of container + liquid               | = 298 g              |
| Mass of liquid                           | = g                  |
| Burette reading before filling container | = 13 cm <sup>3</sup> |
| Burette reading after filling container  | = 45 cm <sup>3</sup> |
| Volume of liquid                         | = cm <sup>3</sup>    |
| Density of liquid                        | = g/cm <sup>3</sup>  |

|                                         |         |
|-----------------------------------------|---------|
| Mass of mug                             | = 200 g |
| Mass of mug + 100 cm <sup>3</sup> water | = 300 g |
| Mass of water                           | =       |
| Volume of water                         | =       |
| Density of water                        | =       |

*No measuring vessel is available, but you have some methylated spirit, a beaker, a Butchart balance, a eureka (displacement) can and twenty 1-cm metal cubes. Describe how you could find the density of the methylated spirit with no additional equipment. (19)*

## Weighing gases

**Demonstration 8.5.** Inflate a bicycle inner tube and attach it to the end of a metre stick balance (Fig. 89). Place 'weights' on the scale pan until the metre stick balances horizontally.

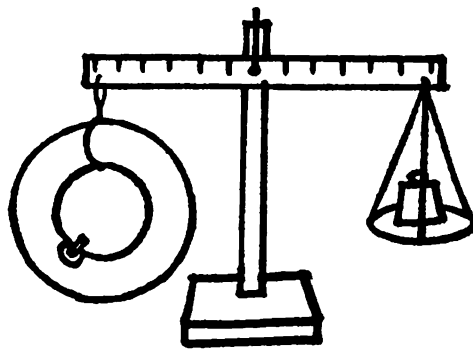


Fig. 89

Now let the air out of the tyre and explain what happens.

Alternatively use a BTL flat pan or similar balance to weigh an inner tube or football bladder empty and inflated. (Such balances are available from W. B. Nicolson.)

### Demonstration 8.6.

(a) For this demonstration you will require a good vacuum pump and a good strong round-bottomed flask which can be sealed. Weigh the flask before and after removing the air from it and find the mass of the air in the flask. Now find the volume of the flask and see if you can work out the density of the air in grams per litre. As it is impossible to get all the air out of the flask your result is not likely to be very good, but it will show you that air does have mass. In fact the air in an average-sized room has about the same mass as you.

(b) A more accurate determination of the density of air may be found by measuring the volume of water which enters the evacuated flask when its clip is opened under water. The volume of water which enters is equal to the volume of air (at atmospheric pressure) which was taken out of the flask by the vacuum pump. What do you think causes the water to enter the flask when the clip is opened?

# Squeezing and stretching matter

## CHAPTER 9

In this chapter we will consider what happens when solids, liquids and gases are *strained*, that is, squeezed, stretched or twisted.

### Properties of solids

Some solids such as wood or brass are so hard that pushing and pulling seems to have little effect on them. They are said to be **RIGID**. Others, like rubber, can be compressed, twisted or stretched but they return to their original shape when released. They are **ELASTIC**. Thirdly, some solids, such as putty, can be pushed into almost any shape and retain their shape. They are **PLASTIC**.

#### **Demonstration 9.1.**

(a) Freeze a rubber ball or piece of rubber tubing in liquid air (nitrogen) or a freezing mixture of solid carbon dioxide and acetone. Now smash the rubber with a hammer.

(b) Stretch a long length of fine wire with a heavy weight and show that it behaves like rubber when the weight is not too great. With very heavy weights the wire behaves more like putty.

Try to obtain, and play with, a piece of 'potty putty' (a compound of silicon, available from Frido or Griffin & George). *What are its properties? (1)*

The terms rigid, elastic and plastic are thus seen to describe the ways in which solids behave under particular conditions.

Here are a few other properties of solids about which you should know, although you need not worry about the names at present.

### Hardness

Some solids are very hard (for example, diamond), while others are soft (for example,

chalk). *Can you think of uses to which these two solids can be put because of those properties? (2)* Diamond and graphite are both carbon. *Why is diamond so much harder? (3)*

### Tensile strength

The cables carrying the Forth Road Bridge must be able to support an enormous load. Compared with, say, copper, steel alloys have a much greater tensile strength, that is, they cannot easily be torn apart. Metals which can be drawn into wires are said to be ductile.

### Malleability

Some materials can be beaten into very thin sheets. Gold is very malleable and can be hammered until it is only one hundred thousandth of a centimetre thick.

### Stretching a solid (Hooke's Law)

Although it is difficult to stretch a straight wire, a spring made by coiling the wire may be stretched easily. Here is an experiment for you to design yourself.

**Experiment 9.2.** Hang up a weak coil spring and attach a brass 'weight' to it (Fig. 90). Measure the increase in length of the spring, that is, the stretch. Put two such 'weights' on the spring and again measure the stretch. Repeat this operation with three, four and five such 'weights' attached. How does the stretch vary with the weight?

Plot your readings on a piece of graph paper (Fig. 91). Do the points obtained suggest a simple pattern? Can you draw a *smooth* line through, or very close to, all the points? Remember that scientists are always trying to discover Nature's secrets, and the simpler those secrets are the better the scientists are pleased!

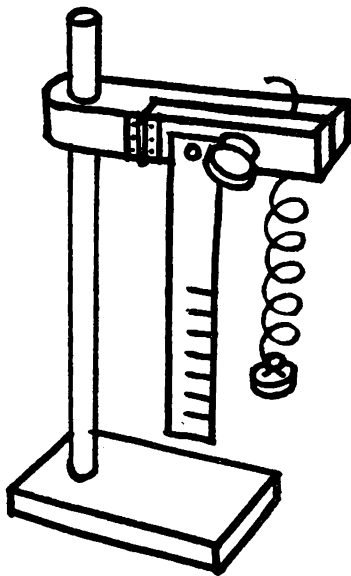


Fig. 90

Complete your graph and try to explain why your line does not go through all the points.

If the force is doubled what happens to the stretch? With three times the force how is the stretch affected? The two quantities, force and stretch, are said to be directly proportional.

Stretch/force for a coil spring

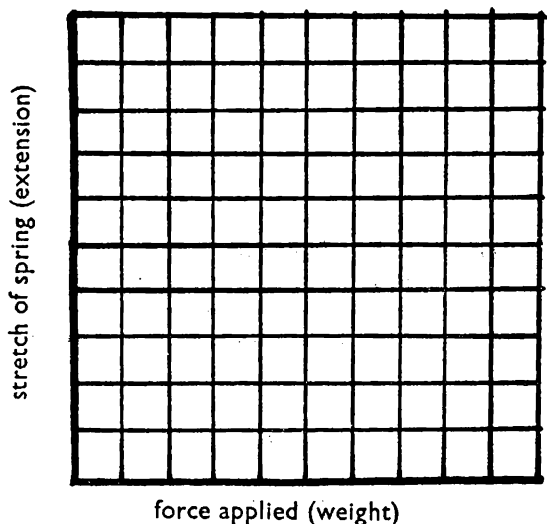


Fig. 91

An Englishman, Robert Hooke, discovered this relationship about 400 years ago. It is sometimes called 'Hooke's Law'.

Use the graph which you have constructed to find the stretch of the spring when (say) a force of 50 grams force is applied to it. Check your answer by tying a 50 g 'weight' to the spring. Find out from the graph what weight will stretch the spring by (say) 5 cm. Again check your prediction by experiment.

*A vertical spring is 10 in long with nothing attached to it. It is stretched to (not by) 12 in when a 1-lb 'weight' is attached. What length will it be when 'weights' of (1) 2 lb, (2) 4 lb and (3) 5 lb are attached? (4)*

*What 'weights' must be attached to the above spring to make the length of the spring (1) 11 in, (2) 15 in and (3) 16 in? (5)*

*If a 3-lb 'weight' was hanging on the above spring and an extra 3-lb 'weight' was added, what would be (1) the extra stretch and (2) the total stretch? (6)*

## Squeezing a liquid

Liquids refuse to be squeezed. Put in textbook language, their 'compressibility is so small that they are generally considered to be incompressible'. Nevertheless it has been estimated that if sea-water could suddenly become *really* incompressible the level of the seas would rise almost 100 feet.

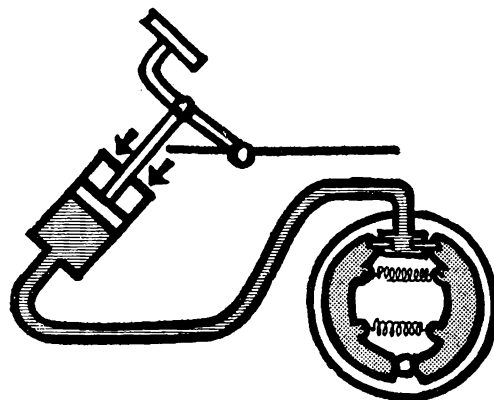


Fig. 92

When a force, or rather a pressure, is applied to a liquid the pressure is transmitted through the liquid. The hydraulic brakes of a car depend on this fact (Fig. 92).

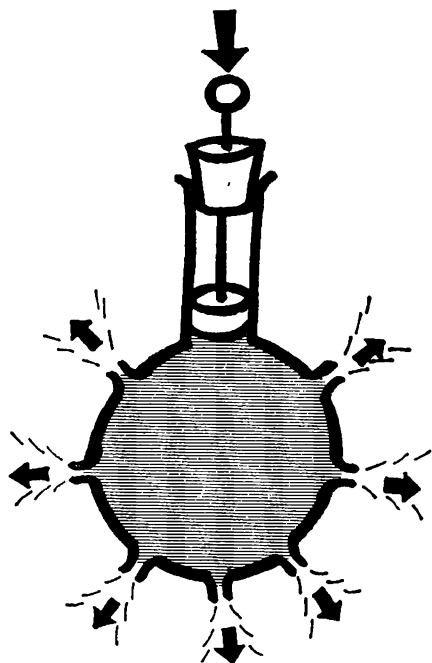


Fig. 93

**Demonstration 9.3.**

(a) Pascal's syringe shows that pressure is transmitted equally in all directions through a liquid. When the piston is pushed in, water spurts out of all the holes with equal force (Fig. 93).

(b) Alternatively, pierce a number of holes in a rubber balloon and force water into it.

**Pressure**

As we have introduced the word *pressure* perhaps we ought to say how it differs from *force*. Pressure is measured by the force pushing against every square centimetre (or square inch) of area. The force is pushing at right angles to the area in question. If a force of 50 grams-force (written as 50 gf) pushes against 10 square centimetres the force on every square centimetre is  $\frac{50}{10} = 5$  gf. The pressure is 5 grams-force per square centimetre (5 gf/cm<sup>2</sup>).

In the new British system of units pressure should be expressed in pounds-force per square inch (lbf/in<sup>2</sup>) or pounds-force per square foot (lbf/ft<sup>2</sup>). In practice, pressure is still often expressed in lb/in<sup>2</sup>. A force of 100 lbf acting on 5 square inches would produce a force of  $\frac{100}{5} = 20$  pounds-force on every square inch. The pressure would therefore be 20 pounds-force per square inch (lbf/in<sup>2</sup>).

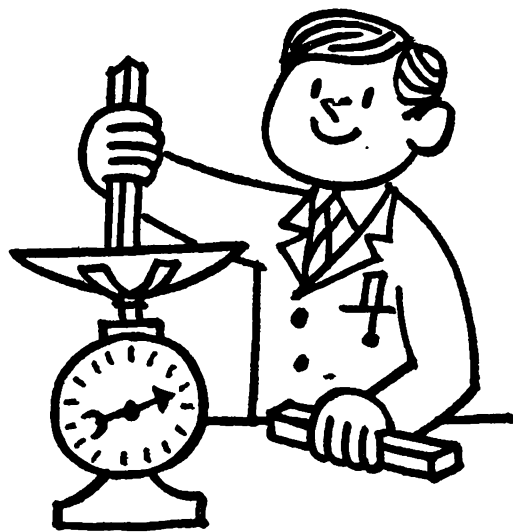
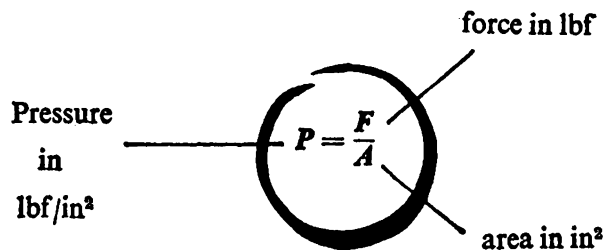


Fig. 94

**Experiment 9.4.** For this experiment you will require blocks of wood with square ends  $\frac{1}{4}$  in  $\times$   $\frac{1}{4}$  in,  $\frac{1}{2}$  in  $\times$   $\frac{1}{2}$  in, and 1 in  $\times$  1 in. Find out what downward force you can exert on a Salter balance with a block of wood held in one hand when your arm is fully stretched (Fig. 94). Now apply approximately the same force with the 1-in-square block of wood to a slab of Plasticine. Repeat this performance with the  $\frac{1}{2}$ -in and  $\frac{1}{4}$ -in blocks.

If you push down with a force of 10 lbf on 1 sq in, the pressure you apply will be  $\frac{10}{1} = 10$  lbf/in<sup>2</sup>.

If the same force is applied to  $\frac{1}{2}$  in  $\times$   $\frac{1}{2}$  in =  $\frac{1}{4}$  sq in, the pressure is  $\frac{10}{\frac{1}{4}} = 10 \times \frac{4}{1} = 40$  lbf/in<sup>2</sup>.

If the area is  $\frac{1}{4} \times \frac{1}{4} = \frac{1}{16}$  sq in the pressure will be  $\frac{10}{\frac{1}{16}} = 10 \times \frac{16}{1} = 160 \text{ lbf/in}^2$ .

The pressures are therefore 10 lbf/in<sup>2</sup>, 40 lbf/in<sup>2</sup> and 160 lbf/in<sup>2</sup>. With what force (or thrust) are you pushing down each time? On which of those two quantities, force or pressure, does the distortion of the Plasticine depend?

*Why is it less painful to carry a heavy case by the handle than by a wire wrapped round the case? (7) Explain why stiletto heels are more likely to mark the floor than flat heels. (8) Why does a sharp knife cut more easily than a blunt one? (9) Why is it more comfortable to lie in bed than sit on a wire fence? (10)*

*A stud on a stiletto heel measures 0.1 in  $\times$  0.1 in. What pressure will be exerted by this stud if an eight-stone girl puts all her weight on it? Express your answer in tons-force per square inch. (11)*

*If a man weighing ten stones stands on an ice skate the blade of which is 0.2 in wide and 10 in long, what pressure does he exert? Give your answer in lbf/in<sup>2</sup>. (12)*

*A pressure of 50 gf/cm<sup>2</sup> is exerted on a rectangular area 3 cm  $\times$  2 cm. Find the total force (or thrust) exerted on the area. (13)*

*A pressure of 77 gf/cm<sup>2</sup> is exerted on an area of 11 cm<sup>2</sup>. What is the thrust? (14)*

*On what area must a force of 800 gf act to produce a pressure of 16,000 gf/cm<sup>2</sup>, that is 16 kgf/cm<sup>2</sup>? (15)*



Fig. 95

## Fluid pressure

You have probably surprised your friends at Christmas parties with this blow-out toy.

A long paper tube is curled up under the action of a fairly weak spring. The harder you blow into the tube the farther it uncurls (Fig. 95). This is really a simple kind of pressure gauge. A Bourdon pressure gauge is simply a tube of spring steel coiled up like the paper tube in the toy. When a fluid pressure is applied to the end of the tube it uncurls and operates a pointer (Fig. 96).

Examine the pressure gauges on a hydrogen or oxygen cylinder.

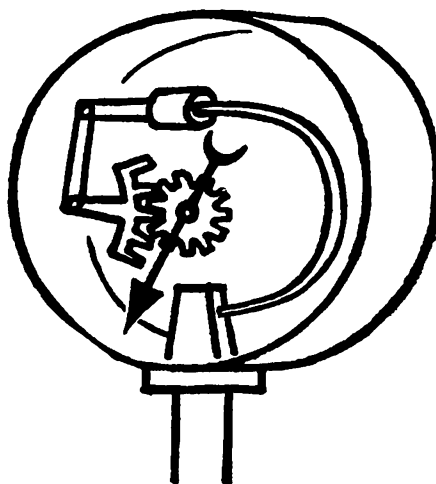


Fig. 96

**Demonstration 9.5.** Use a Bourdon pressure gauge to measure the pressure in a car tyre. Let out some of the air and read the pressure again.

**Demonstration 9.6.** Connect 8 ft of heavy glass tubing to a pressure gauge reading up to 15 lbf/sq in approximately (Fig. 97). Pour water into the tube to a height of 2 ft and note the pressure. Find the pressure with 4 ft, 6 ft, and then 8 ft of water.

Now repeat this experiment with suitable depths of carbon tetrachloride and mercury. What is the density of (a) water, (b) carbon tetrachloride and (c) mercury?

Complete this table of results.

| Depth of liquid | Water pressure | Carbon tetrachloride pressure | Mercury pressure |
|-----------------|----------------|-------------------------------|------------------|
| 2 ft            |                |                               |                  |
| 4 ft            |                |                               | //////////       |
| 6 ft            |                |                               | //////////       |
| 8 ft            |                |                               | //////////       |

From these results what do you think happens to the pressure in a liquid as the depth increases? How does the density of a liquid affect the pressure at a given depth?

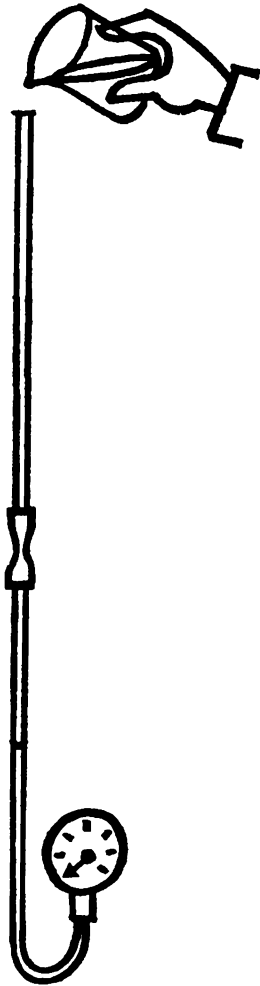


Fig. 97

We may summarise these results by saying

that the fluid pressure increases as the depth and density increase.

You may sometimes see pressure expressed as so many centimetres or inches of mercury or feet of water. This means that the pressure in question is the same as the pressure due to a column of mercury or water of the depth stated. Because pressure depends on depth, the depth of a liquid is sometimes taken as a measure of pressure. You can construct a simple pressure gauge based on this principle.

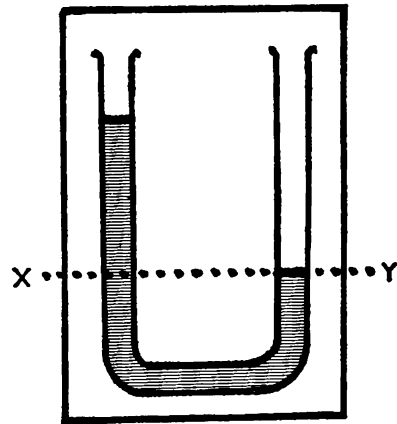


Fig. 98(a)

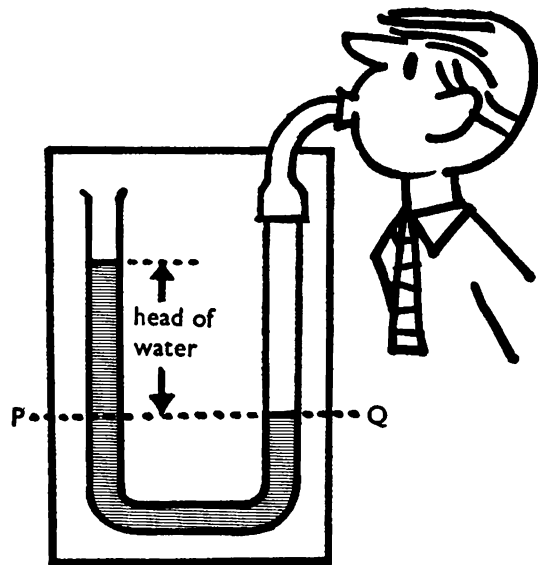


Fig. 98(b)

#### Experiment 9.7.

(a) A glass U-tube is partially filled with water. Let us suppose that the water settles

down as shown in Fig. 98 (a). What could you say about the pressure at  $X$  compared with the pressure at  $Y$ ? If the pressure at  $X$  is greater than at  $Y$ , the water will flow from  $X$  to  $Y$  until the two pressures are equal. Try this experiment and see if the result is the one you predicted.

(b) Now connect a piece of rubber tubing to one end of the U-tube and gently blow into it (Fig. 98 (b)). The difference in the heights of the two columns is called the head of water. It is 6 in in this case. The pressure at  $P$  must be the same as the pressure at  $Q$  (why?) and so the pressure of your breath is the same as the pressure due to a column of water 6 in deep. It is referred to as a pressure of *six inches of water*.

This type of pressure gauge is called a manometer. Use this manometer to find the pressure of the gas supply. Give your answer in inches of water.

*A length of rubber tubing is connected to a gas tap. A short length of glass tubing is now attached to the rubber tube. The glass tube is lowered into a long measuring cylinder full of water and the gas turned on. Explain how such a piece of apparatus could be used to measure the gas pressure. (16)*

The water supply has usually far too great a pressure to measure with a small water manometer. Can you suggest another liquid you might use in the manometer such that the head would be much smaller for a given pressure applied? (17)

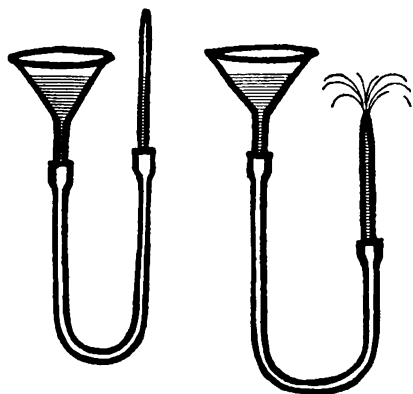


Fig. 99

**Demonstration 9.8.** Connect a piece of glass tubing drawn out to a fine nozzle and a filter

funnel to a length of rubber tubing as shown in Fig. 99. Fill the apparatus with water and observe the height of the water jet when the end of the glass tube is held below the level of the water in the filter funnel. Why does the water jet nearly reach the level of the water in the funnel? Why does it not reach this level?

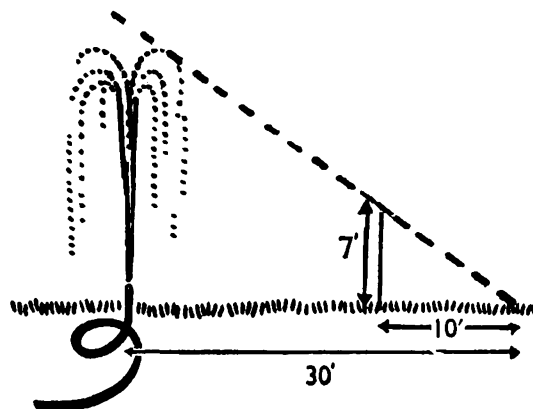


Fig. 100

**Experiment 9.9.** To obtain a rough estimate of the water pressure from a garden hose you could try the experiment illustrated in Fig. 100. Adjust the nozzle until you get the highest jet of water possible and use the triangulation method discussed in Chapter 3. Why is this method very rough? What is the water pressure of the supply illustrated here? (18)

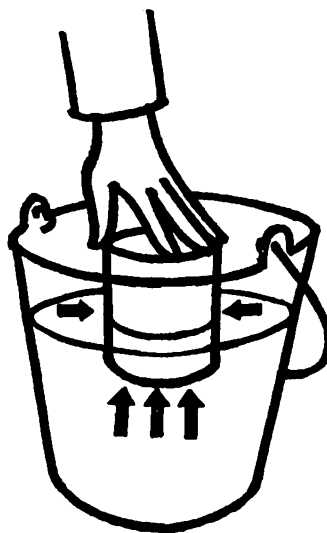


Fig. 101



## Flotation

**Experiment 9.10.** Take an empty tin can and float it in a bucket of water. Try pushing the can down into the water (Fig. 101). What happens?

The pressure on one side of the can will be exactly equal to the pressure on the opposite side at the same depth so that we can ignore sideways pressure for the moment. What does the fact that the can is pushed upwards tell you about the pressure and hence the force on the bottom of the can? This upward force or thrust is called upthrust. How does the upthrust alter as you push the can down until it is almost submerged?

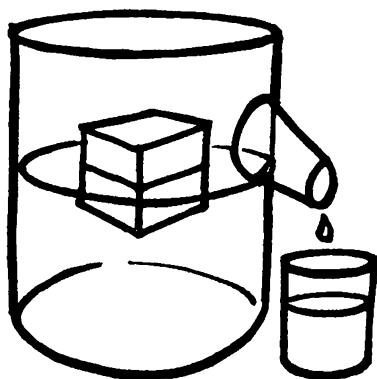


Fig. 102

**Experiment 9.11.** For this experiment you will require a eureka (displacement) can filled with methylated spirit.

Weigh an empty beaker and a block of wood. Gently lower the block into the methylated spirit and collect in the beaker the methylated spirit which is displaced. Re-weigh the beaker and contents. Calculate the weight of methylated spirit displaced. Repeat this experiment with pieces of cork, paraffin wax, polythene and aluminium. Make a table of results and indicate whether the solid floats or sinks.

What does this experiment tell you about the weight of the liquid displaced when the solid floats?

Repeat this experiment using water in place of methylated spirit and record your results in a similar table.

|                                      | Wood | Cork | Paraffin wax | Polythene | Aluminium |
|--------------------------------------|------|------|--------------|-----------|-----------|
| Weight of beaker empty               |      |      |              |           |           |
| Weight of beaker and displaced meth. |      |      |              |           |           |
| Weight of meth. displaced            |      |      |              |           |           |
| Weight of solid                      |      |      |              |           |           |
| Solid floats or sinks                |      |      |              |           |           |

**Experiment 9.12.** Find the densities of the solid blocks used in Experiment 9.11. Remember that, when we know the weight, we know the mass. Construct another table as shown.

|                                      | Wood | Cork | Paraffin wax | Polythene | Aluminium |
|--------------------------------------|------|------|--------------|-----------|-----------|
| Density of solid ( $\text{g/cm}^3$ ) |      |      |              |           |           |
| Density of meth. ( $\text{g/cm}^3$ ) | 0.8  | 0.8  | 0.8          | 0.8       | 0.8       |
| Floats or sinks in meth.             |      |      |              |           |           |
| Density of water ( $\text{g/cm}^3$ ) | 1.0  | 1.0  | 1.0          | 1.0       | 1.0       |
| Floats or sinks in water             |      |      |              |           |           |

From the results you have just obtained, when would you say that a solid floats on a liquid?

**Demonstration 9.13.** Try to float a rubber stopper in water and then in carbon tetrachloride. Find the density of the rubber, water and carbon tetrachloride, and see if the answer you gave to the last question agrees with the result of this experiment. (WARNING: Carbon tetrachloride is a poison.)

*The density of lead is  $11.3 \text{ g/cm}^3$ , of iron  $7.8 \text{ g/cm}^3$ , of gold  $19.3 \text{ g/cm}^3$ , and of mercury  $13.6$*

$\text{g}/\text{cm}^3$ . Which, if any, of those solids floats in mercury? (19)

Why is it more comfortable to lie in a bath of water than on a hard floor? (20)

**Experiment 9.14.** Try to float an egg in water. Now dissolve salt in the water until the egg floats. What does this experiment tell you about the density of an egg?

**Demonstration 9.15.** Pour some mercury, carbon tetrachloride, water and oil into a measuring jar and allow them to settle. Now drop in pieces of iron, rubber, paraffin wax and cork. What can you say about the densities of these liquids and solids?

### Why do steel ships float?

We have discovered that solids and liquids will float on denser liquids. It is possible, however, for steel to float on water, yet steel is denser than water. Try the following experiment.

**Experiment 9.16.** Take a lump of Plasticine and try to float it in water. Now press it into the shape of a hollow boat and see if the boat floats. Weigh the boat and place it in a eureka can filled with water to measure its displacement. Weigh the water displaced as before and compare it with the weight of the boat.

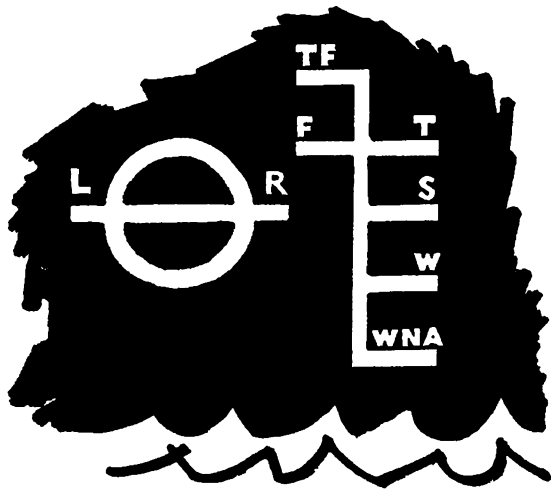


Fig. 103

If you have examined the side of a merchant ship you may have noticed the Plimsoll lines (Fig. 103). The ship must not be loaded so that the appropriate line is below the water surface. LR is the Lloyd's Register mark. The other letters represent the loading lines for fresh and salt water at different temperatures. *Explain why the fresh water marks (TF=tropical fresh and F=fresh) are higher than the salt water marks. (21) Why are the marks for warm water (T=tropical and S=summer) above the marks for cold water (W=winter and WNA=winter in the North Atlantic)? (22)*

Before a solid will float in a liquid the weight of the liquid displaced must be equal to the weight of the solid. This discovery is called the Law of Flotation and is sometimes stated as follows.

### Law of Flotation

When a body floats in a liquid it displaces its own weight of the liquid.

**Experiment 9.17.** Take a piece of aluminium foil (silver paper) and fold it into a small hard block. Will it float on water? Now open up the foil and crumple it into a ball. Why does it float now?

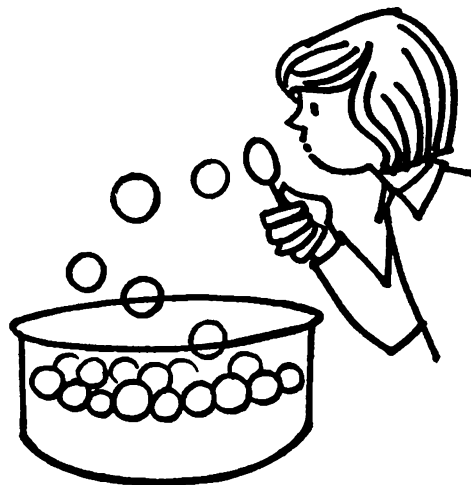


Fig. 104

**Demonstration 9.18.** Pour a little carbon tetrachloride into a large glass jar. Now blow some soap bubbles and allow them to float down into the jar (Fig. 104). Explain the

results you see. What does the experiment tell you about carbon tetrachloride vapour? (Remember that carbon tetrachloride is a poison.)

## Gas pressure

Of the three states of matter gas is the most easily squeezed.

**Experiment 9.19.** Take two bicycle pumps and reverse the washers on one of the plungers. Seal the outlets and try pushing and pulling the pistons. Can you explain the difference in the two cases? Explain why a bicycle pump can be used (outside school) to fire a paper pellet.

Robert Boyle has been called 'the Father of Chemistry and the Son of the Earl of Cork'. He studied the 'spring' of air and discovered a simple connection between the pressure and the volume.

## Kinetic theory

In every cubic centimetre of ordinary air there are about  $3 \times 10^{19}$  molecules! Let us consider what happens when a gas such as air is trapped in a closed box. The gas molecules are continually flying around and some will bump into the sides of the box. The sides of the box should, therefore, receive millions of tiny bumps. The total effect of those collisions

is that the sides of the box feel an outward push; that is, a pressure is exerted on them. If more gas is forced into the container there will be more molecules, more collisions, and therefore the pressure will be greater. This is what happens when you blow up a balloon or a car tyre.

Consider a cylinder full of gas. This is illustrated in Fig. 105 (a). The pressure is noted and the piston then pushed up to the second position (Fig. 105 (b)). All the molecules are now pushed closer together. *How do you think this will affect the number of molecular bumps on the cylinder walls each second?* (23) *What would you expect to happen to the gas pressure?* (24) *Describe how you would test your answer by experiment.* (25)

## The atmosphere

Around the Earth there is a thick blanket of air which is a mixture of gases. It consists mainly of nitrogen (just under 80 per cent) and oxygen (about 20 per cent). Both are important for all living things. The air we breathe in contains 20 parts of oxygen, but our lungs absorb about 4 parts, so that we breathe out air with only 16 parts of oxygen and about 4 parts of carbon dioxide. Our breath also contains water vapour. *How can you demonstrate this?* (26)

During the day plants take in carbon dioxide so that, on the average, air contains only about 0.04 per cent of this gas. Water vapour is present in varying amounts over the Earth's surface. It may be practically non-existent or it may represent as much as 4 per cent of the air.

For simplicity the Earth's atmosphere may be divided into four sections using altitudes of 10, 50 and 500 miles as approximate limits.

(1) The first 10 miles is called Troposphere. Here the temperature gets less and less as we go up. All weather changes take place here: winds, rain, clouds, storms.

(2) From 10 to 50 miles up is called the Stratosphere. Here there is practically no water vapour or clouds. The winds blow always in the same direction and the temperature is low and constant.

(3) From 50 to 500 miles is called the Iono-

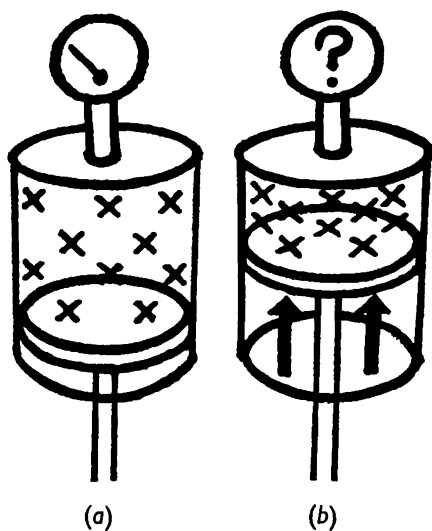


Fig. 105

sphere. Here electrically charged (that is ionised) layers reflect radio waves back to Earth.

(4) The Exosphere is the name given to the region above 500 miles high. The Van Allen Belts are here.

From a variety of sources we know that the air does not have the same density all the way up. If the density of all the air were the same as the density at sea level the height of the atmosphere would be only five miles. Yet some snow-capped mountains are higher than this, so water vapour must exist above five miles high. Airscrew-driven planes also fly above this height, showing that air is present. Balloons, rockets and satellites have given us a great deal of information on the structure of the atmosphere, and it is certain that it extends for a hundred miles or more. The density of the air becomes less and less as we leave the Earth.

### Air pressure

Do we really live at the bottom of a sea of air weighing many millions of tons? Does the Earth's gravitational field really pull the air towards it? Is atmospheric pressure fact or fiction? To answer those questions you must try a few simple experiments.

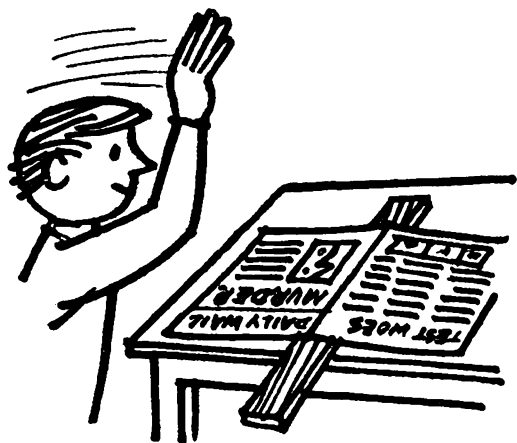


Fig. 106

**Experiment 9.20.** Lay a strip of wood from (say) an orange box on a bench so that the end projects over the edge as shown in Fig. 106. Carefully smooth out a newspaper on top of it. Whack the projecting end of the stick and see

what happens. What forces are acting on the stick?

**Experiment 9.21.** Attach a spring balance to a rubber sucker. Moisten the sucker and press it firmly on a flat surface such as metal or plate glass. The liquid layer ensures that most of the air is pushed out between the two surfaces. Now see what force is necessary to pull them apart. Estimate the area of the sucker and find an approximate value for the air pressure in pounds force per square inch.

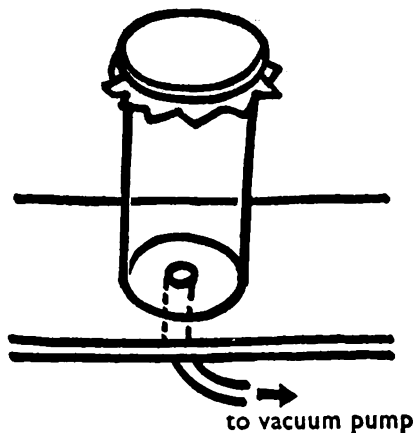


Fig. 107

**Demonstration 9.22.** Stretch a piece of balloon rubber over one end of a glass jar which has two open ends (Fig. 107). Remove the air from the jar and explain any changes in the shape of the rubber membrane.

**Experiment 9.23.** Soak an egg in vinegar overnight or use a hard-boiled egg with its shell removed. Now soak a small piece of cotton wool in methylated spirit. Light it and drop it into a wide-necked milk bottle or flask. Place the egg (sharp end down) on the mouth of the bottle (Fig. 108). Explain the results you observe.

### Experiment 9.24.

(a) Boil a little water in a thin-walled tin can. The steam will drive out the air. Now cork the can tightly, remove the source of heat and cool the can by pouring cold water over it. The steam will condense leaving a partial vacuum inside the can. Draw diagrams showing the can before and after the experiment and explain the difference.

(b) Here is an alternative experiment.  
Pour a small quantity of methylated spirit into a plastic (liquid soap) bottle and lower



Fig. 108

it into a can of boiling water. When the meth boils its vapour will drive out the air in the bottle. Leave the meth to boil for a few seconds, then cork the container and remove it from the boiling water and lay it on a bench.

Can you explain what happens when the methylated spirit vapour condenses? Draw

diagrams of the plastic bottle before and after the experiment.

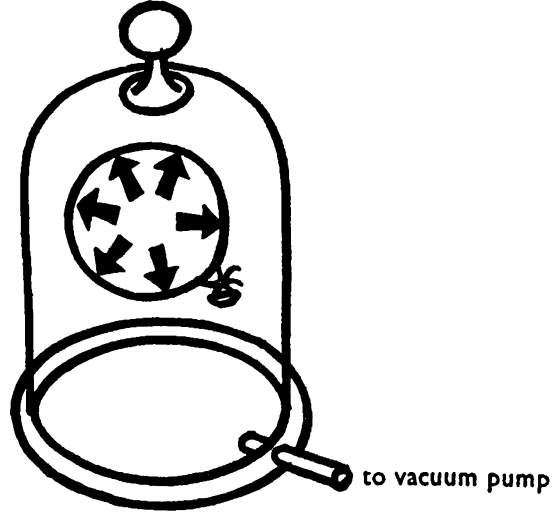


Fig. 109

**Experiment 9.25.** Place a partially blown-up balloon in a bell jar. Remove the air from the jar and explain the change which takes place (Fig. 109). Does the air inside the balloon appear to push equally in all directions? On what evidence did you base your answer?

About 300 years ago the Mayor of Magdeburg, Germany, did a very spectacular experiment. Having invented the first vacuum pump he used it to remove the air from two large

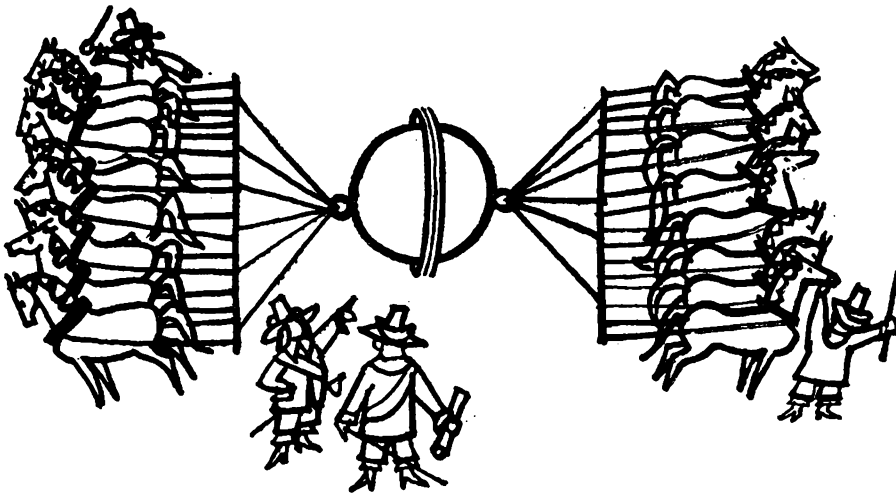


Fig. 110

hollow hemispheres fitted together to form an air-tight sphere. Two teams of eight horses were needed to separate the hemispheres when he conducted his experiment before the Emperor of Germany (Fig. 110). You can try a similar experiment using small model hemispheres or two plumber's force-cups pushed together to remove most of the air. *Why is it difficult to separate the hemispheres?* (27)

*An air-filled bottle is corked and placed in a bell jar. If the air is pumped out of the bell jar what will happen?* (28)

*A tumbler is filled with water and a flat card placed over the top. Explain what happens when the tumbler is inverted.* (29)

*Why does a liquid not run out of a vertical piece of glass tubing if you place your finger over the top end?* (30) *Why does milk flow up a drinking straw?* (31)

*Explain the way in which a vacuum cleaner picks up dust.* (32)

### Measuring atmospheric pressure

You have used one direct method of measuring the atmospheric pressure with a spring balance. *What was it?* (33) A similar method uses a bicycle pump with the washer reversed and the outlet sealed. The pump is held vertically and the piston pulled down. An approximate value for the atmospheric pressure may be obtained by finding (a) the force necessary to pull the plunger down and (b) the area of the washer on which the force is acting. Normally the air pressure is about 15 pounds-force per square inch. If you take a bar of mild

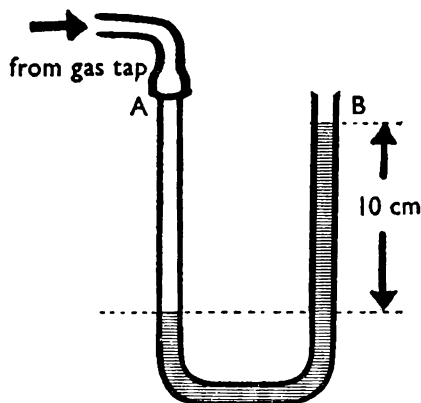


Fig. 111

steel 1 inch square and 53 inches long and let it stand on its end it will exert about the same pressure as the atmosphere.

Another method of measuring the atmospheric pressure is to use a manometer. Such an instrument really measures the *difference* between two pressures.

In the manometer illustrated in Fig. 111 the difference between the gas pressure (in tube A) and the atmospheric pressure (in tube B) is equal to the pressure exerted by a column of water 10 centimetres high. This is sometimes referred to as a pressure of 10 centimetres of water. In practice it is quite normal not to mention that this is really the gas pressure in *excess* of the atmospheric pressure. When a motorist refers to his tyre pressure as 25 pounds-force per square inch he means (although he may not know it) 25 pounds-force per square inch *more* than the 15 pounds-force per square inch atmospheric pressure. The actual pressure in the tyre is therefore 40 pounds-force per square inch.

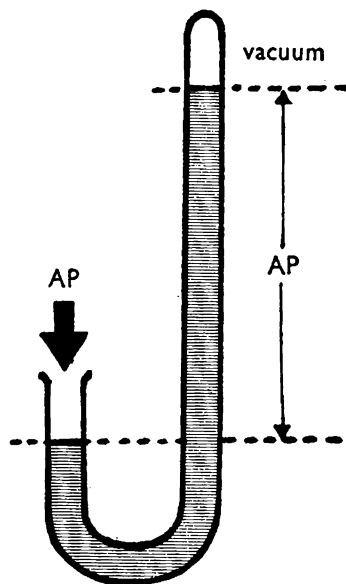


Fig. 112

Could we use a manometer to measure atmospheric pressure itself? To do this we should have to arrange the apparatus so that it measured the difference between atmospheric pressure and nothing! This is exactly what we

do. One side of the manometer is sealed and all the air removed by replacing it with mercury.

As there is no need to have a long tube filled with air, the manometer is more conveniently constructed as a J-tube (Fig. 112). The difference in the two levels gives a measure of the atmospheric pressure. It is normally about 76 centimetres (30 inches) of mercury.

**Demonstration 9.26.** To construct a simple barometer it is not even necessary to have a J-tube. If you have a glass tube about a yard long sealed at one end you can fill it with mercury and use it as a barometer. You will have to make sure that there are no air bubbles in the mercury before inverting the tube in a small basin of mercury. Collect the small air bubbles by running a big bubble slowly up and down the almost filled tube. The barometer when complete will require a metre stick to measure the height of the mercury. Can you decide where the zero of the metre stick should be and why a J-tube is not necessary now? Draw a diagram of your complete barometer and label it carefully.

Most of the barometers used today do not use mercury as it is heavy, expensive and easily spilled. Those commonly used are called aneroid (meaning 'no fluid') barometers. You can build a model aneroid barometer quite simply.

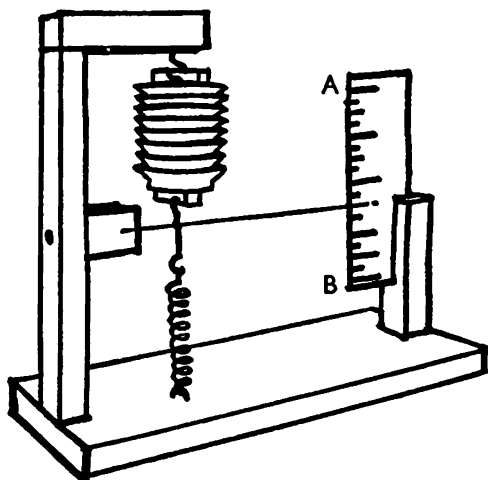


Fig. 113

**Experiment 9.27.** You will require a sealed container which varies in volume as the changing atmospheric pressure pushes against it. A milk bottle with a thin rubber membrane stretched over its mouth, a balloon, or a plastic bellows (Woolworth's whistling concertina) will do nicely. Some way of magnifying the movement must be found and a lever will have to be constructed. One possible model is illustrated in Fig. 113. If the pointer is near the 'A' position, is the atmospheric pressure high or low? Can you think of a way to magnify the movement of the rubber membrane on the milk bottle?

There is one big snag with such model barometers. Surround the container with a cloth soaked in hot water and see if you can discover the defect.

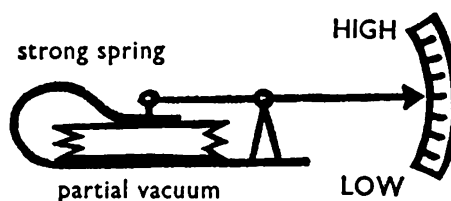


Fig. 114

In a real aneroid barometer the container is a partially evacuated metal box which has a flexible lid held by a strong spring (Fig. 114). Differences in atmospheric pressure cause small changes in the shape of the box. This movement is magnified by a system of levers. As the atmospheric pressure decreases with height aneroid barometers are often used as altimeters in aircraft. The scale is marked in 'thousands of feet' instead of 'inches of mercury'.

*Find out what a barograph is used for and draw a labelled sketch of the instrument. (34)*

### Weather

Long ago weather forecasters used a number of rules to predict the weather. Many of these rules were put to rhyme and so were more easily memorised. Do you know any of those rhymes?

Today thousands of weather stations all over the world on land and sea regularly record temperature, wind speed, humidity and atmo-

spheric (barometric) pressure. This information is then passed immediately to central stations. It is supplemented by readings obtained from balloons, aircraft, rockets and satellites, and used to produce weather forecasts. Changes in atmospheric pressure are more important than actual atmospheric pressure, so readings are taken several times each day.

As the density of water vapour is less than that of dry air a falling pressure indicates that some water-vapour molecules have replaced some air molecules. This suggests that rain or snow is likely. Low-pressure areas are called depressions or *lows*. Such regions often tend to move from west to east at about 30 miles an hour. They cannot, however, be relied on always to do this.

The higher-pressure air round a depression spirals inwards and pushes the water vapour upwards. *Why?* (35) The water vapour then condenses and produces rain. Increasing atmospheric pressure often indicates cloudless skies and dry weather. High-pressure regions are called anticyclones or *highs*. They start when the air is cooled. The cool, dense air then gradually falls and produces a wind which spirals outwards towards areas of low pressure.

Lows and highs are shown on weather maps by drawing lines joining all the places that report equal pressures. These lines are called *isobars* (Fig. 115).

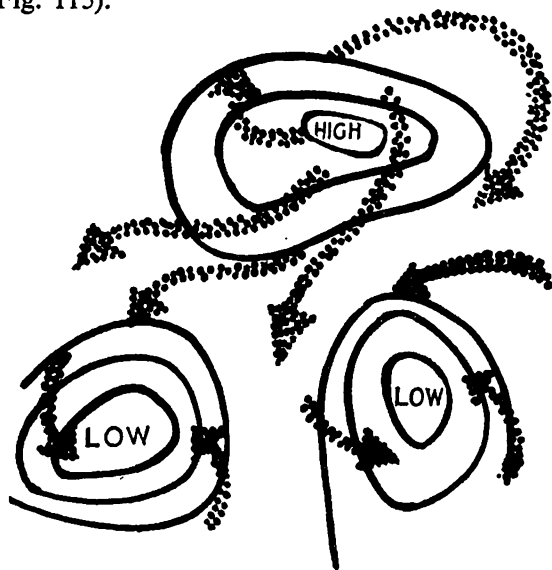


Fig. 115

Study a weather map and see if you can identify any depressions or anticyclones.

**Experiment 9.28.** Using a piece of glass or rubber tubing connect the mouths of two football bladders, one blown up and the other not. In what direction does the air move? Why does a bicycle tyre collapse when the valve is removed?

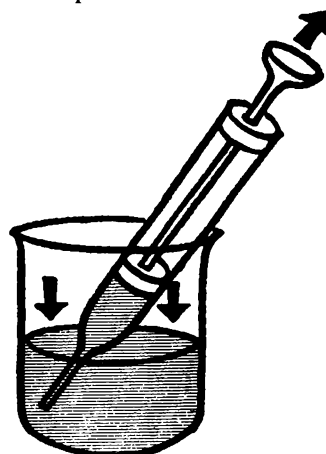


Fig. 116

### Pumps and pistols

If the piston of a syringe is pulled upwards and if no air is allowed to enter from the

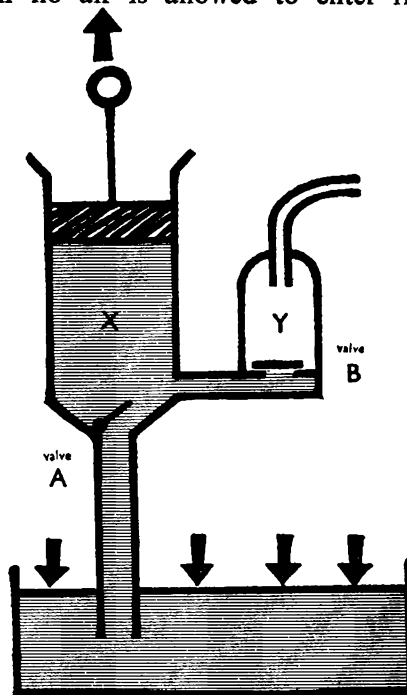


Fig. 117



bottom the space below the piston will become a low-pressure region. The much greater atmospheric pressure may then push a liquid into this space. If the piston is now pushed downwards the syringe may be used as a kind of primitive water pistol. It will, of course, have to be recharged each time it is used.

Imagine a very long syringe with a perfectly fitting piston. *To what height could the atmosphere push water up into such a syringe? (36)* *If a loaded syringe were inverted, to what height could the water be forced by the piston? (37)*

### Force pump

In order to maintain a more or less constant supply of water from a well a force pump is

used. This is a syringe with two valves added to it (Fig. 117). Modern water pistols are similar in construction.

The valves open when the pressure below them is greater than the pressure above them. When the piston is pulled upwards chamber *X* becomes a low-pressure region and valve *A* is therefore opened by the water which is being forced up the inlet pipe by the atmospheric pressure. The atmospheric pressure will keep valve *B* closed during this operation. *When the piston is pushed down what would you expect to happen (a) to each of the valves, (b) to the water in chamber X and (c) to chamber Y? (38)* *Why do you think the outlet pipe protrudes into chamber Y? (39)*

# Heating matter

## CHAPTER 10

### Heating solids

Most metals and other solids expand when they are heated. You have already devised one experiment using a retort stand and straw pointer which showed that an iron bar expands when it is heated.

**Experiment 10.1.** When an electric current is passed through a fine Constantan wire the wire heats up. Stretch a yard of wire between two retort stands and attach a small object, such as a nut or bolt, to the middle of the wire. Pass a current of several amps through the wire and see what happens. What happens when the current is switched off? Why?

**Experiment 10.2.** Obtain tubes of glass, copper (or brass) and iron (or steel). They should be of the same length. Devise an experiment to find which tube expands most and which least when heated through the same temperature range, for example, room temperature to  $100^{\circ}\text{C}$ .

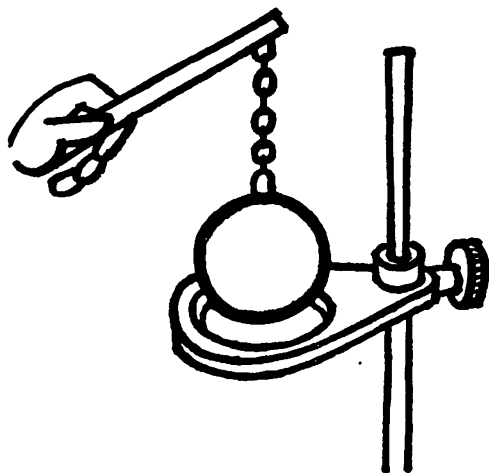


Fig. 118

It is not only the length of a solid which increases when it is heated, as may be seen from the following demonstration.

**Demonstration 10.3.** A metal ball will just slip through a metal ring when both are at room temperature (Fig. 118). The ball is now heated in a gas flame and then placed on the ring. What happens? Why? After a short time the ball slips through the ring yet the ball is still hot. Explain this.

Because of the expansion and contraction of steel the Forth Railway Bridge could be nearly four feet longer on a hot summer's day than it is in winter. To avoid the disastrous buckling which would occur if no allowance were made for such expansion the ends of the bridge rest on rollers.

When boiling water is poured into a thick glass bottle the bottle often breaks. The inside of the bottle expands when the hot water touches it, but the outside is still cold, as heat does not travel through the glass very quickly. The glass is therefore strained and so cracks and breaks. Special kinds of glass, such as Pyrex, have been developed for oven-ware. They are not so liable to break when heated as they expand very little.

### Expansion and molecular forces

When a metal bar is heated the molecules vibrate more violently. They take up more room and the bar expands. When the temperature is reduced the molecules are drawn closer together. As a metal contracts it exerts a tremendous force just as it did when it expanded.

The following experiment demonstrates just how large a force is exerted when a steel bar contracts.

**Demonstration 10.4.** A strong iron frame holds a steel bar, one end of which is threaded. The other end is held by a cast-iron pin (Fig. 119). The bar is removed and strongly heated on a gas ring. It is then replaced in the iron cradle and the nut tightened as much as

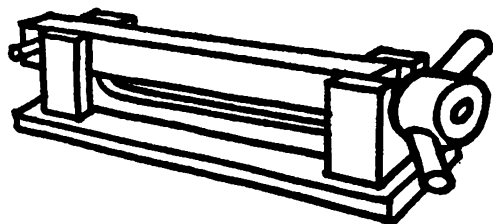


Fig. 119

possible. The bar is allowed to cool. At first nothing appears to happen. Remember that even steel can be stretched. Explain the final result of this demonstration.

Some versions of this apparatus are fitted with built-in gas jets. The bar may thus be heated in the cradle and the result of thermal expansion demonstrated.

*Why is pitch poured between the small sections of a concrete motorway? (1) Explain why oil pipe lines sometimes have large loops or bellows in them. (2) Can you describe two examples, other than those already mentioned, of precautions taken to prevent damage resulting from thermal expansion? (3)*

*Find out how steel tyres are fitted to the wheels of railway engines. (4)*

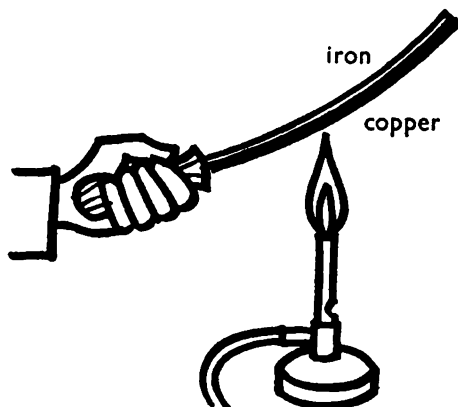


Fig. 120

### Bimetallic strip

**Experiment 10.5.** Take a bimetallic strip (two metals joined together) and heat it (Fig. 120). If the bar bends in the direction shown, what does this tell you about the expansion of the copper compared with the iron?

When heated through a certain temperature range some metals expand, per foot, more than others. *Why must we say 'per foot' here?* (5) It is because of this difference in the expansion of copper and iron that the bimetallic strip bends when heated.



Fig. 121

Bimetallic strips are used to control temperatures (thermostats), to operate fire alarms, to measure temperatures (thermometers) and to switch flashing trafficator lamps off and on. The illustration shows a thermostat fitted to a smoothing iron (Fig. 121). When the temperature rises the strip bends upwards and breaks the circuit; when it cools down the circuit is again completed. The gap width is controlled by a knob on top of the iron. The size of this gap governs the length of time the iron is off and hence the average temperature of the iron.

*Draw a diagram showing how a bimetallic strip could be used (a) to control the temperature of a fish tank and (b) to indicate room temperature. (6)*

### Melting

Metals and many other solids eventually melt when heated to a sufficiently high tempera-

ture. Different solids change to liquids at different temperatures. The melting temperatures of solids may be used to distinguish one material from another. *Name three substances which you have seen melting when they were heated.* (7) *Can you name a metal which is liquid at normal room temperature?* (8)

The metal filament of an electric lamp must be capable of reaching a very high temperature without melting. For this purpose tungsten is used, as it melts at  $3,380^{\circ}\text{C}$ . Designers of jet engines and rockets are continually looking for metals which can be heated to extremely high temperatures without melting.

Most substances expand still further when they melt. There are however a few exceptions, which include iron and ice. Cast-iron objects have clean edges because the liquid metal expands when it solidifies in the moulds. The metal type used by letterpress printers is made from an alloy which expands when it solidifies. *Why?* (9) It is because ice expands when it freezes that pipes burst in the winter and ice floats on water. Milk in a bottle left outside on a cold winter's night may freeze. As it freezes it expands and forces the milktop off the bottle.

## Heating liquids

### Expansion

#### Experiment 10.6.

(a) Fill a small flask with methylated spirit. Push a piece of glass tubing through a stopper and fit it to the flask. Some of the meth will rise into the tube (Fig. 122). Mark the level of the meth in the tube with a rubber band and plunge the flask into a mug of hot water. Observe carefully what happens to the level of the meth (i) immediately the flask enters the water and (ii) a few seconds later. Can you explain your observations in terms of expansion of glass and expansion of meth?

(b) Repeat this experiment using a plastic (liquid detergent) container filled with water. Can you explain any difference you observe?

**Experiment 10.7.** Obtain four glass tubes each with a bulb on the end. They should all be the same size. Fill them to the same level

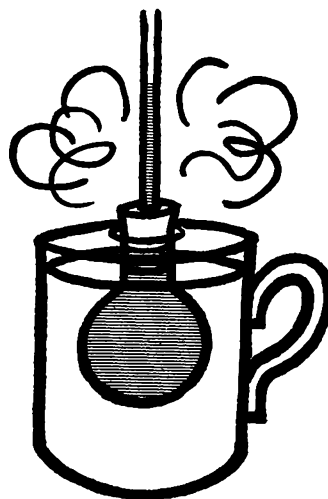


Fig. 122

with methylated spirit, paraffin, water and mercury. Plunge the bulbs into a bath of hot water and record the final increase in level of the different liquids.

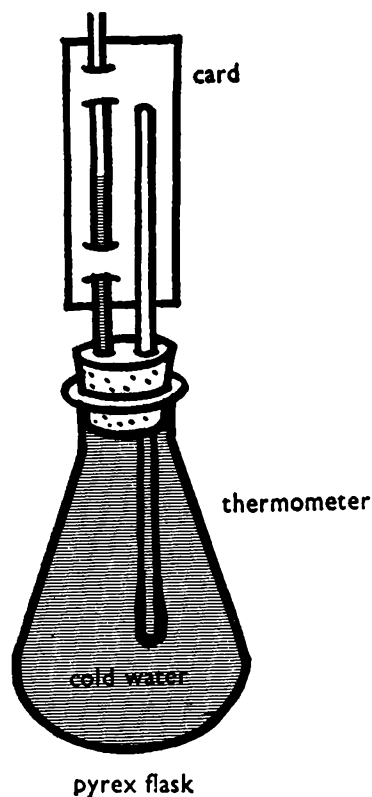


Fig. 123

**Demonstration 10.8.** Draw out a piece of glass tubing and insert it, together with a thermometer, into a rubber stopper (Fig. 123).

Fill a Pyrex flask with cold water and insert the stopper so that the water is pushed about half way up the narrow part of the glass tube as shown. Now attach a piece of white card to the tube to enable you to mark the water level. Surround the flask with a freezing mixture of ice and salt and mark the water level in the tube every degree Centigrade.

At what temperature is the volume of the water in the flask least? What happens to the water below that temperature? What can you say about the density of water at that temperature?

These experiments have shown that when liquids are heated they normally expand. As with solids, the expansion for a given volume varies from liquid to liquid when they are heated through the same temperature range. *Does a given volume of mercury expand more or less than an equal volume of water when heated through the same temperature range?* (10) *What about the expansion of alcohol?* (11)

### Change of state

**Experiment 10.9.** Mix some melting ice with salt and observe the temperature. How does the temperature compare with the temperature of the ice alone?

Take a small aspirin bottle. Fill it with cold water and screw on the cap. Place the bottle in the freezing mixture and leave it for some time completely surrounded by ice and salt. Explain the result obtained.

**Experiment 10.10.** Try to find the temperature at which the following liquids boil: (a) water, (b) brine, (c) methylated spirit. Why must you be particularly careful when boiling methylated spirit? You should use a water bath to heat it.

Prolonged heating of a liquid causes the temperature to rise until it boils. *Into what does it change?* (12) Since a pure liquid has a definite boiling point this can be used to help identify it. Different fuel oils are obtained from petroleum by separating them at different

boiling temperatures. *Which boils at the lower temperature, water or methylated spirit (alcohol)?* (13)

### Changes in boiling point

**Experiment 10.11.** Boil a solution of salt and water and determine the boiling point. How does this compare with the boiling point of pure water?

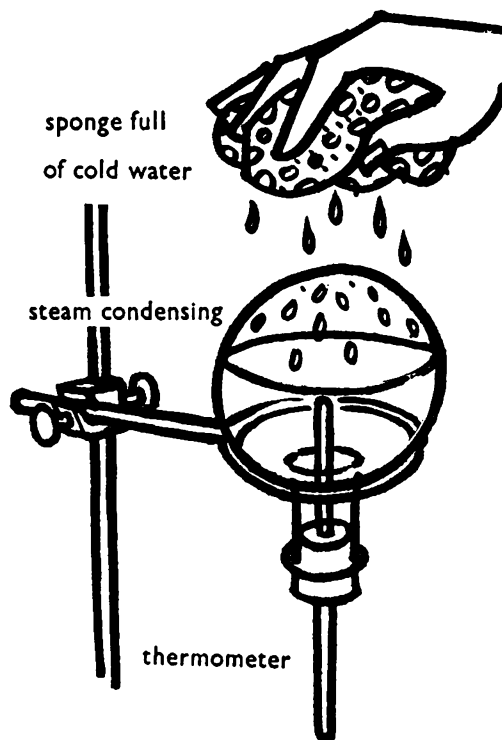


Fig. 124

**Demonstration 10.12.** Boil some water in a round-bottomed flask and, when the steam has driven out the air, firmly stopper the flask and *immediately* remove the bunsen. Invert the flask as shown in Fig. 124 and when the water stops boiling pour some cold water over the top. This cold water will cause the steam to condense, thus reducing the pressure inside the flask. What is the lowest temperature at which you find the water still boiling?

The temperature at which a liquid will boil may be altered by (a) adding an impurity or

(b) altering the pressure applied to the liquid. Inside a pressure cooker the pressure is greater than atmospheric pressure and the boiling point of water is raised to about  $150^{\circ}\text{C}$ . In a railway engine water can boil at  $200^{\circ}\text{C}$ . On top of a high mountain the pressure is much lower than it is at sea level. *How do you think this would affect the boiling point of water on a mountain? (14) Could you boil an egg on top of a high mountain? (15)*

### Evaporation

Some liquids can change quickly into vapour without reaching their boiling temperatures. They are said to be *volatile*.

**Experiment 10.13.** Put a little ether on the back of your hand and blow on it. As it evaporates, a liquid takes in heat from the surroundings, in this case your hand.

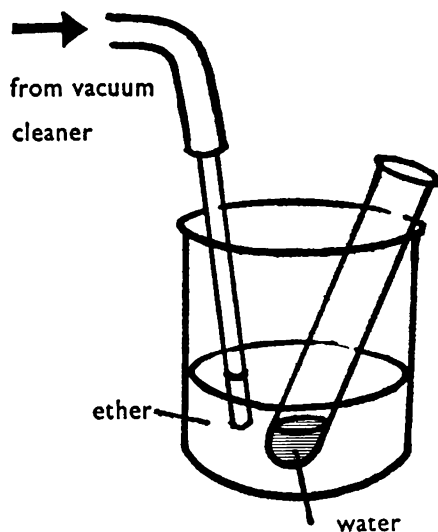


Fig. 125

**Demonstration 10.14.** Put a little water in a small test tube and place it in a beaker containing ether. Use a vacuum cleaner to blow air through the ether, thus causing it to evaporate quickly. What happens to the water in the test tube? Why?

Conduct this experiment in a ventilated room in which there are no naked lights.

In eastern countries water is kept in porous jars. As the water gradually seeps through to

the outside, it evaporates and takes heat from the water left in the jar, thus keeping it cool. *Can you think of any other applications of this principle? (16)*

### Heat and temperature

Earlier in the course you boiled water and continued heating it after it boiled. *What happened to the temperature? (17)* Heat energy is needed to change a liquid into a vapour or gas, yet the temperature does not rise while the change is taking place.

**Experiment 10.15.** Put 50 g and 500 g of cold water in two identical beakers. Using two bunsen burners with the same size of flame heat each beaker for one minute. Now change over the bunsen burners or the beakers and continue heating for a further minute. You have put approximately equal quantities of heat into each beaker of water. Read the final temperatures and explain the difference.

**Experiment 10.16.** In the above experiment we heated different masses of the same material (water). Now put 200 g of water in one beaker and 200 g of mercury in another and heat them over similar bunsen flames for 15 seconds. Stir the liquids as you heat them and report the final temperatures obtained. Lead shot or small copper chips may be used instead of mercury.

We have seen that heat may cause substances to expand, to change state and to become hotter. When heat energy is given to a substance the molecules move about more quickly. It is the increased speed of the molecules which gives us the sensation of warmth or hotness.

Consider the illustration of a large petrol-driven coach and a racing motor cycle (Fig.

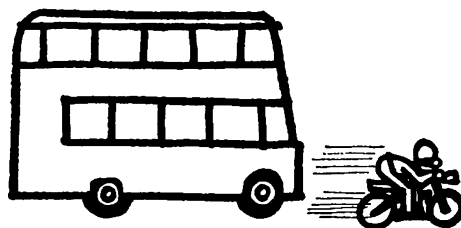


Fig. 126

126). In going one mile, which is likely to use more petrol (chemical energy)? (18) Which goes more quickly, the bus or the bike? (19) More energy (petrol) does not necessarily mean greater speed.

In the case of heat we have seen that the same amount of heat (energy) can result in different changes in temperature (molecular speed) if the heat is applied to different masses or different substances.

## Temperature measurement

How can we measure the speed of the molecules? As they are too small to be seen even through a powerful microscope, we must use an indirect method of measuring their speed, that is, we measure something that happens when the molecules speed up. The measure of hotness or warmth is called temperature. Every temperature-measuring device depends

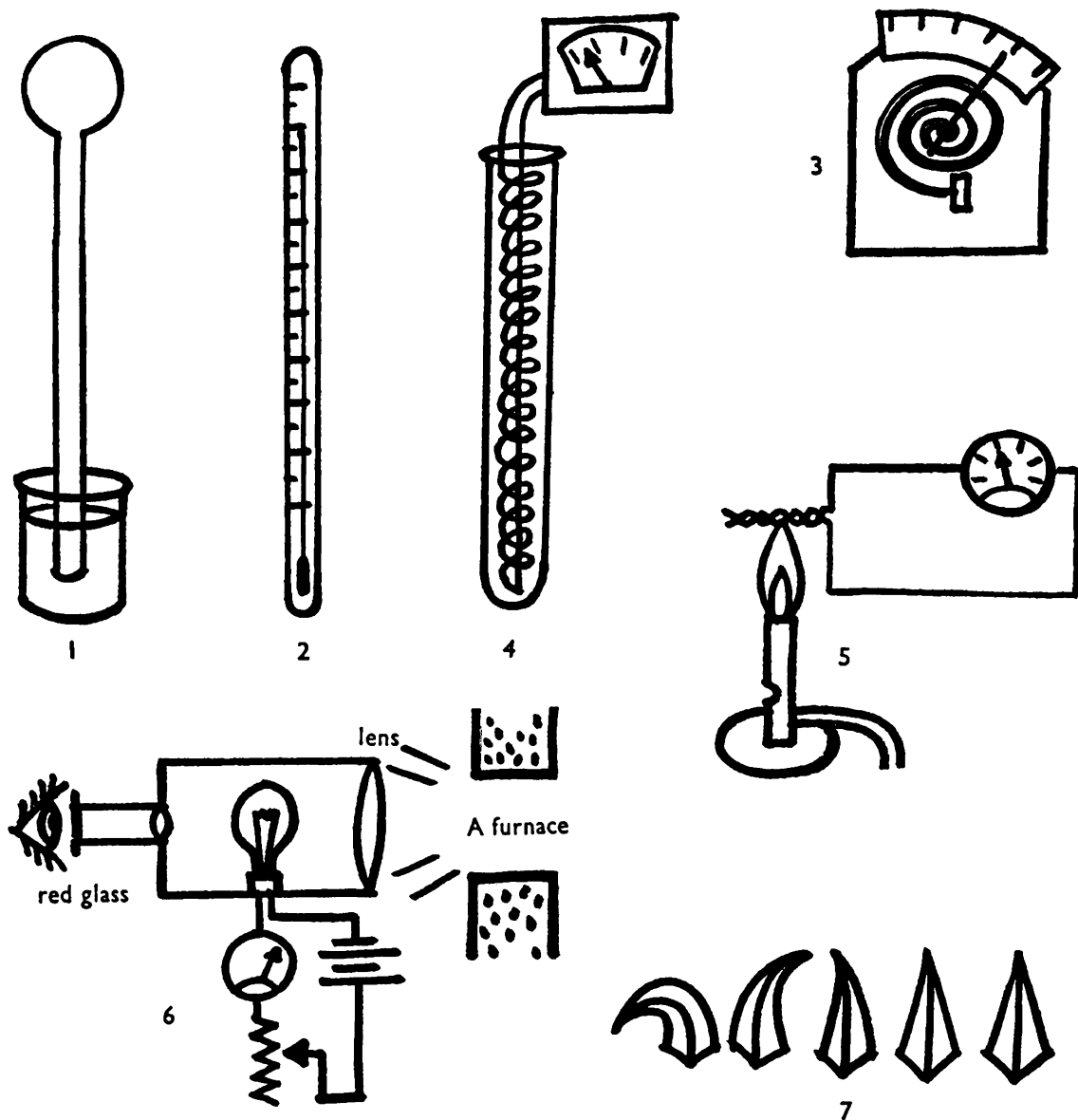


Fig. 127

upon a change being made in a substance when it gets hot.

**Experiments and demonstrations 10.17.** Here are seven changes which enable us to measure temperature.

(1) *Change in pressure of a gas.* Galileo's thermoscope (Fig. 127 (1)). Dip the end of the tube into coloured water. Gently heat the bulb by placing your hands round it. Explain what happens. Now remove your hands and some of the water will rise into the tube. You should try to arrange the heating so that the coloured water rises about half-way up the tube. The apparatus should now be clamped in position with a burette stand. What will happen to the liquid in the tube when the air temperature rises? Why? Can you suggest any disadvantage of this thermometer?

(2) *Change in volume of a liquid.* A mercury thermometer (Fig. 127 (2)).

(3) *Change in lengths of two solids.* A bimetallic strip as used in a Rototherm thermometer (Fig. 127 (3)).

(4) *Change of electrical resistance of a solid.* A resistance thermometer (Fig. 127 (4)).

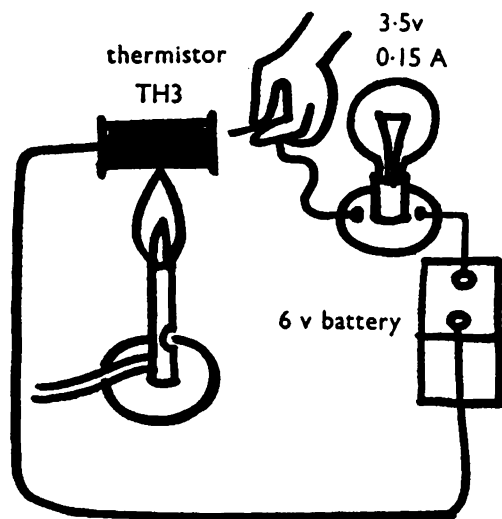


Fig. 128

Connect a thermistor in a circuit as shown in Fig. 128 (Type T.H.3 from Radiospares is suitable). Now heat the thermistor with a bunsen burner and watch the bulb. What has happened to the resistance of the thermistor?

Wind a coil of iron wire, such as soft galvanised 'tying wire' obtainable from ironmongers, and connect it in a circuit as shown in Fig. 129. Watch the lamp as the coil is heated with a bunsen burner. What happens to the resistance of the wire as its temperature rises?

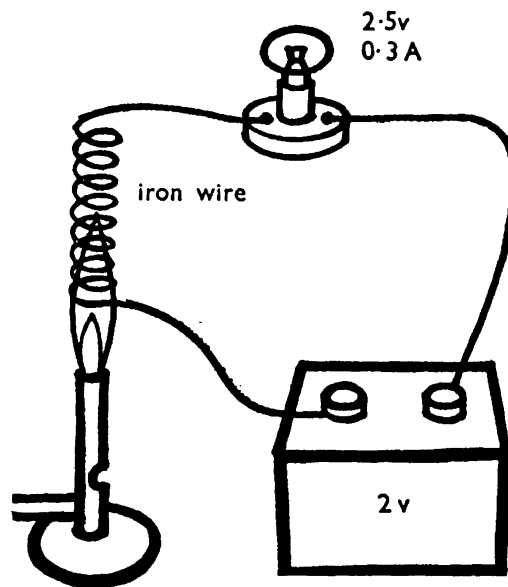


Fig. 129

Some solids have a greater and some a smaller resistance when they are heated. The change in resistance with temperature can be used to measure temperature.

(5) *Change of electrical potential (voltage) between different metals.* A thermocouple.

A simple thermocouple thermometer may be constructed by joining two wires of different metals (Fig. 127 (5)). Iron and Constantan wire can be used to make a thermocouple which will operate with a milliammeter (maximum reading = 1 mA). Use this instrument to detect the warmest part of a bunsen flame.

(6) *Change in colour.* An optical pyrometer (Fig. 127 (6)).

Watch the colour of an electric radiator element when it is switched off.

(7) *Change in state.* Use a range of clay cones each with a different melting temperature (Fig. 127 (7)). To find the approximate temperature of (say) an oven you would note which cones melt and which do not.



The most common thermometers use the change in volume of a liquid. *Which liquids are most often used? (20) What are the boiling points and melting points of those liquids? (21)*

### Calibration of a thermometer

**Experiment 10.18.** Take an uncalibrated mercury thermometer. Attach a card to it with adhesive tape and mark on the card the melting point of ice ( $0^{\circ}\text{C}$ ) and the boiling point of water ( $100^{\circ}\text{C}$ ). Draw the apparatus you use and explain how you use it. Divide your scale into ten equal parts and use your thermometer to measure the temperature of your body. Check your measurement by using a clinical thermometer. (Suitable uncalibrated thermometers L41-900 are available from Griffin & George.)

The Fahrenheit thermometer is still used to some extent and you should have some idea of how the scale was constructed. Fahrenheit of Danzig tried to obtain the lowest temperature possible with a freezing mixture. He called this lower fixed point  $0^{\circ}$ . He then used blood temperature as the upper fixed point. *Why were those fixed points not satisfactory? (22)* On the Fahrenheit scale the melting point of ice is  $32^{\circ}\text{F}$  and the boiling point of water is  $212^{\circ}\text{F}$ .

Celsius was a Swedish astronomer and his Centigrade system is coming into general use in this country. Here are some temperatures on the Centigrade scale.

|                       |                 |
|-----------------------|-----------------|
| $-10^{\circ}\text{C}$ | Bitterly cold   |
| $0^{\circ}\text{C}$   | Very cold       |
| $10^{\circ}\text{C}$  | Bearable        |
| $20^{\circ}\text{C}$  | Pleasantly warm |
| $30^{\circ}\text{C}$  | Hot summer day  |
| $40^{\circ}\text{C}$  | Sweltering      |

*Using graph paper draw a graph showing the relationship between the Centigrade and Fahrenheit scales. (23) Use your graph to convert the following temperatures given in degrees Celsius (Centigrade) into degrees Fahrenheit: (a)  $10^{\circ}\text{C}$ , (b)  $60^{\circ}\text{C}$ , (c)  $75^{\circ}\text{C}$ . (24)*

*Convert the following temperatures into degrees Celsius: (a)  $41^{\circ}\text{F}$ , (b)  $68^{\circ}\text{F}$ , (c)  $98.4^{\circ}\text{F}$ . (25) What is the special significance of the last-mentioned temperature? (26)*

D

## Heating gases

When a gas is heated the molecules move more quickly. The pressure may then change or the volume may alter. Under certain circumstances both pressure and volume are altered. In order to study the effect of heat on a gas we will try to keep one or other of these two variables constant.

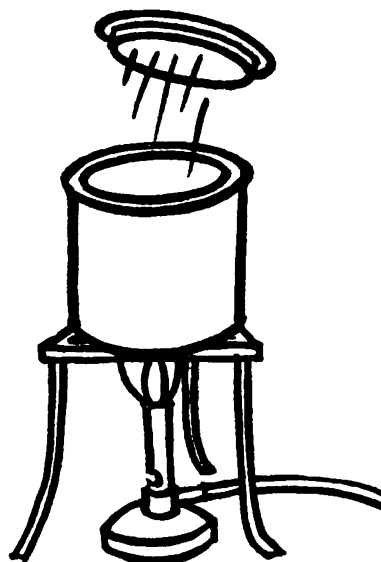


Fig. 130

**Demonstration 10.19.** In this demonstration you can study the effect of heating a constant volume of air in a coffee tin (Fig. 130). The lid should be fitted just tight enough to ensure the tin is airtight. What does the result tell you?

**Demonstration 10.20.** Three different gases are to be heated through the same temperature range. The pressure is constant at atmospheric pressure throughout, and the original volume of each gas is the same. An equal volume of vacuum pump oil is poured into three identical flasks, which are then fitted as shown in Fig. 131. The oil has such a low vapour-pressure that it can be ignored. One flask should be filled with air, another with coal gas and the third with carbon dioxide. The gases may be introduced through the long tubes, the clips being left open until the flasks are full of gas.

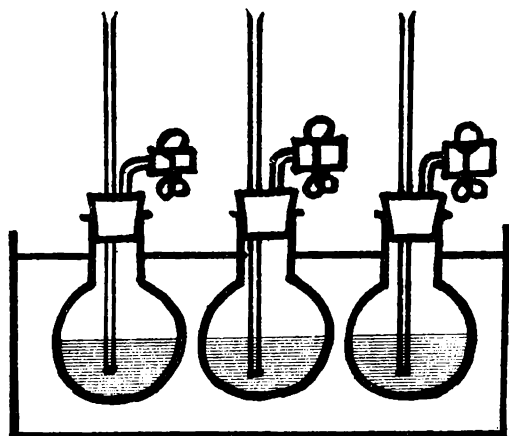


Fig. 131

The three flasks should then be placed in a box into which hot water is poured until the flasks are covered (Fig. 131). Note the final height to which the oil rises in each tube. What does

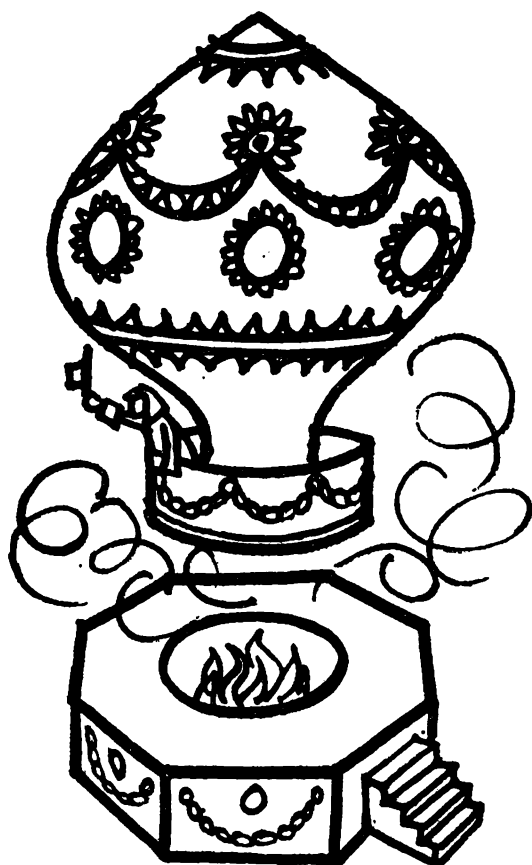


Fig. 132

the result suggest happens to equal volumes of gas at the same pressure when they are heated through the same temperature range?

**Experiment 10.21.** Here is an experiment in which both pressure and volume change. Fix the mouth of a balloon over the neck of a large round-bottomed flask and immerse the flask in hot water. Explain the result obtained.

**Experiment 10.22.** Nearly 200 years ago two Frenchmen, Joseph and Etienne Montgolfier, made a hot-air balloon which carried a chemist 80 ft into the air.

It is possible to build a model hot-air balloon from thin tissue paper. If you are a keen model maker you might like to try to design one. It should be about 6 ft high and have an opening at the bottom. A wire or balsa-wood cage should be fitted to the opening and a piece of Metafuel placed in the cage to heat the air in the balloon. Why does a hot-air balloon rise? Why is a gas-filled balloon only partially filled when it leaves the ground? How does the density of the gas in such a balloon compare with the density of air at sea level?

The experiments you have conducted show that when a gas is heated it may expand or exert a greater pressure than before. A car engine utilises the increase in pressure of a heated gas to drive the piston in the cylinder. The heat comes from the explosion (rapid burning) of petrol vapour when ignited by the spark plug.

**Demonstration 10.23.** You should see this experiment demonstrated.

A Perspex tube represents the cylinder of an internal combustion engine. Two bolts are screwed into the sides to act as the sparking plug. The ends should be about a quarter of an inch apart. The high voltage necessary to provide the spark may be obtained from an induction coil. The piston is a piece of cork or hardboard fitting loosely into the cylinder and held by a wire on top of the tube (Fig. 133).

To operate the model lift out the piston and turn on the gas for a second or two. Turn off the gas and replace the piston. Now stand clear and switch on the induction coil! It may be necessary to experiment once or twice with

different mixtures of gas and air until a suitable explosive mixture is obtained.

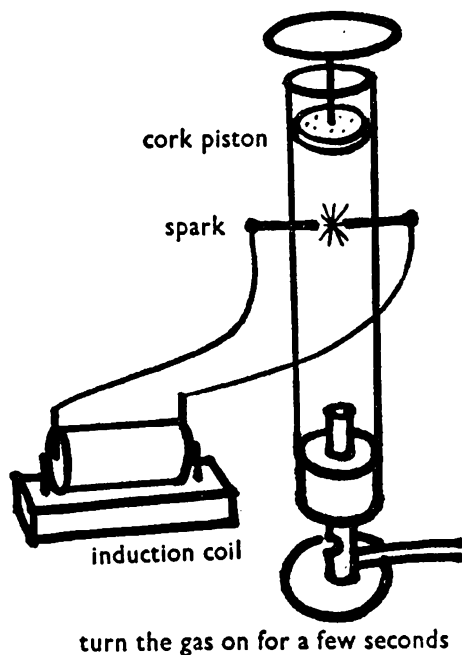


Fig. 133

turn the gas on for a few seconds

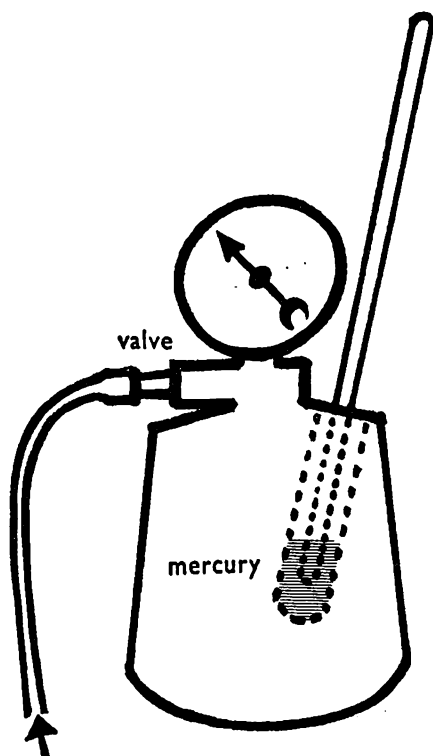


Fig. 134

### Compressed air

**Experiment 10.24.** Hold the end of a bicycle pump which you are using to blow up a tyre. As you compress the air in the pump what happens to its temperature?

#### **Demonstration 10.25.**

(a) A strong metal cylinder is fitted with a Bourdon pressure gauge and an inlet valve from a car tyre. A brass tube large enough to hold a thermometer projects into the cylinder. Some mercury is poured into this tube and a thermometer inserted. Pump air at room temperature into the cylinder and note any change in temperature. Why was the mercury poured into the tube?

(b) An alternative piece of apparatus may be built from a strong metal container, such as an old fire-extinguisher. An air thermometer is used to indicate rise or fall of temperature as shown in Fig. 135.

Before fitting the flask into the container, hold your hands round the flask for a few moments to allow some of the expanded air

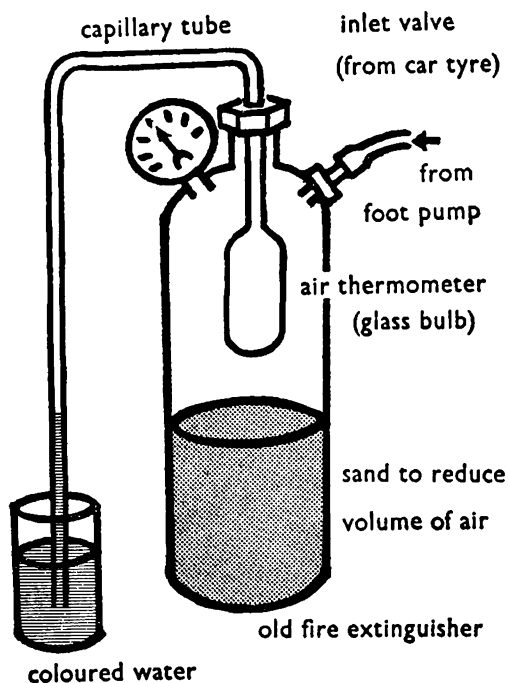


Fig. 135

to bubble through the coloured water. When the air cools water will rise to the position shown.

Fit the flask back in the container and note the water level in the capillary tube. Now pump some air into the container and watch for any change in the level of the water in the tube. Does it indicate a rise or fall of temperature?

(c) Pump some air into the container and leave it for half an hour or so, until you are sure the air inside has reached the room temperature. Now release the air in the container, and see whether the change of level of the water in the capillary tube indicates a rise or fall of temperature inside the container.

Will a cricket ball rebound at greater speed when struck by a stationary bat or one moving towards it? If we regard gas molecules as tiny bodies striking the walls of their containers, then their average speed will be increased if one of the walls moves inwards. If the average speed of the molecules increases, the temperature rises. Thus, whenever a gas is compressed the molecules speed up and the gas becomes hotter.

When a cricket ball strikes a bat which is moving away from it the speed at which it rebounds will be much less. Similarly molecules striking a receding wall will rebound with smaller speeds. When a gas is allowed to expand the average speed of the molecules becomes less, that is, the gas cools down.

## Visual aids

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A suitable filmstrip to illustrate the effect of heat on matter is available from Visual Publications. It is called *Energy and Man*, Part 4: 'Heat and Temperature'.

# Push-push. Pull-pull

## CHAPTER 11

### Forces

A hammer knocks a nail into a wall—a solid has exerted a force. A river washes away a bridge—a liquid has exerted a force. A hurricane sweeps a roof from a house—a gas has exerted a force. Every minute of every day you (a mixture of all three states of matter) are pushing, pulling, twisting, squeezing. *Can you write a list of some of the forces you have exerted in the last few minutes? (1)*

*How would you recognise a force if you met one? (2)*

### Effect on shape

#### Experiment 11.1.

(a) Take a piece of putty or Plasticine and push it with objects of different sizes. When is it deformed most? On what does this deformation depend? What happens when the force is removed?

(b) To a block of Sorbo rubber apply a tension (pull it) and then a thrust (push it). Finally twist the rubber. What happens when the forces are withdrawn?

(c) Exert forces on such things as springs, elastic bands, paper, wood, steel, water and air, and report on their behaviour.

*What kind of material should a ball be made of if it has to bounce? (3) Would a steel ball bounce? (4) Drop a ball-bearing on various different surfaces including steel plate and see if you were correct.*

From the above experiments we see that a substance is altered in shape—deformed—when a force is applied to it. Some substances return to their original shape almost immediately they are released; others, such as putty, paper and wood, are often permanently deformed.

They are squashed, torn, bent or broken. *Can you suggest any changes of shape which could be used as a method of measuring how strong the force is? (5) What instrument have you already used to measure force? (6)*

### Effect on motion

If you want to move a barrow, you push it or pull it. Can you discover how forces affect movement in the following experiments?

#### Experiment 11.2.

(a) Lay a block of wood on the end of a bench. To start it moving along the bench give it a push. Does it go on moving at the same speed? Why is this?

(b) Give a similar push to a ball on the bench. Why is its behaviour different?

(c) Push a balloon puck along a flat polished bench and say why you think it moves so freely.

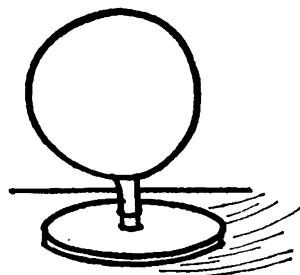


Fig. 136

A balloon puck can easily be constructed from a circular piece of Perspex or hardboard (Fig. 136). Drill a  $\frac{1}{8}$ -in hole in the centre and glue a wood plug or cork over it. The cork, of course, must also be drilled. The balloon may then be fitted to the cork. (Suitable pucks are available from Serinco.)

**Experiment 11.3. Blow football.** Study the movement of a table tennis ball on a bench as

you blow it. Use a drinking straw or cardboard tube, but not a glass tube, for the experiment (Fig. 137). If the ball is at rest when you blow it what happens? If the ball is coming towards

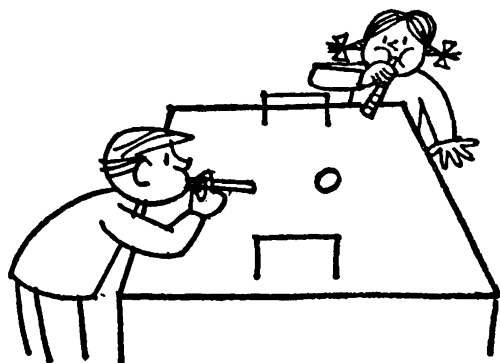


Fig. 137

you when you blow it how is its motion altered? If the ball is moving across the table and you blow it from the side how does it move?

By blowing on the ball you have exerted a force on it. *State three things that can happen to a table tennis ball when a force is exerted on it.* (7)

### Shape and motion

Forces alter shape and motion. A body can be dented, stretched, twisted, broken or torn

by forces. A body which is at rest can be made to move and a moving one can be slowed down, stopped or have its course altered by forces. As detectives we must now watch out for those things and when we see them we can be sure that the culprit is a force.

### Types of force

For simplicity we can consider forces as being of two types: (a) contact forces, and (b) action at a distance.

#### (a) Contact forces

In the first group come all the forces we have dealt with so far. Contact forces arise when the molecules of one body come into contact with those of another. They can be transmitted only through solids, liquids or gases. In this group are forces which tend to slow things down. Those include frictional forces which are usually called just 'friction'. The following experiments show how friction acts in solids, liquids and gases.

**Experiment 11.4.** Pull a block of wood along a bench at a steady speed using a spring balance (Fig. 139). Note the force required. Place a book on top of the block and again see what

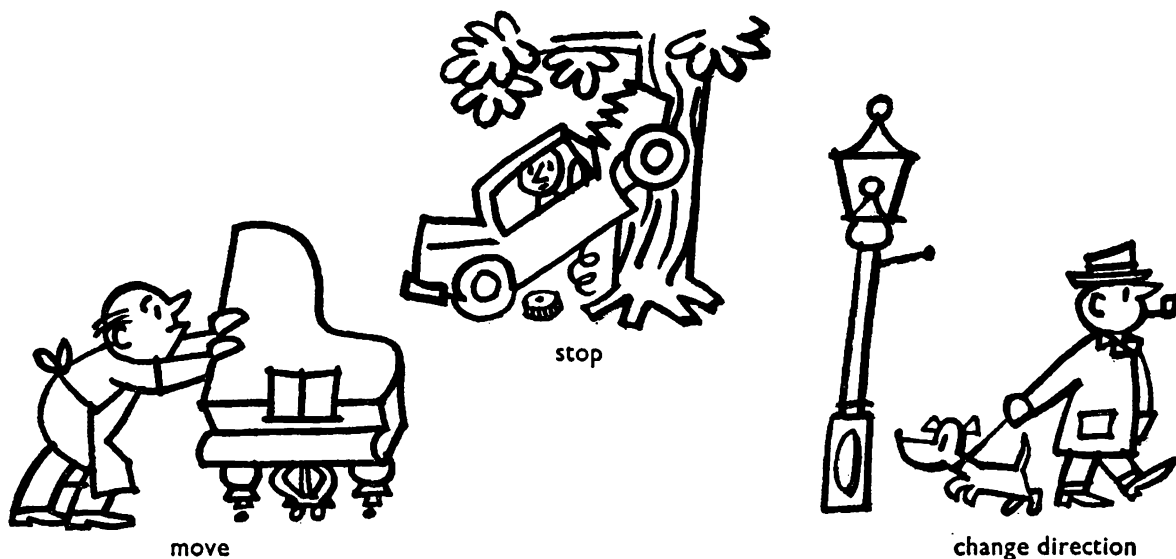


Fig. 138

force is needed to pull it at constant speed. Repeat this experiment with two, three and four similar books on the block of wood.

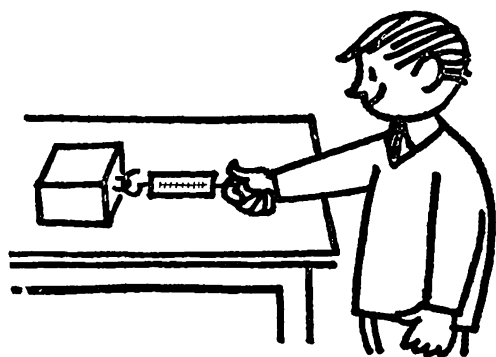


Fig. 139

If you examine even a smooth surface under a microscope it looks more like a mountain range than a level road (Fig. 140). When two such surfaces are in contact some of the

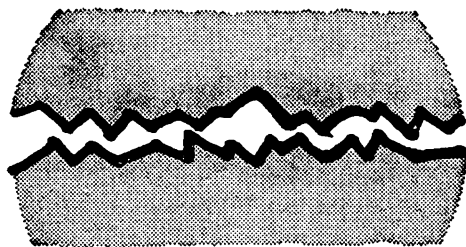


Fig. 140

mountain peaks collide and stick together if the pressure is great enough. The surfaces are then held together by adhesion. Most of the force needed to move one surface on another is used to break those tiny welds.

**Experiment 11.5.** Take two flat pieces of metal and rub them together. Now press them together firmly with your hands and try again. At the point of contact (mountain peaks) the metals melt, that is they are welded together. The forces of adhesion between the molecules holds the surfaces together.

Now oil the metal surfaces and rub them together. Can you explain the difference in the friction?

**Experiment 11.6.** Drop some ball-bearings

through a tall jar of water and through a jar of glycerine or Polycell. What differences do you observe? What does this tell you about the glycerine? Do the balls fall at the same speed in air as in water?



Fig. 141

**Experiment 11.7.** Hold a piece of paper vertically by the top edge and move it slowly and then quickly through the air (Fig. 141). What do you observe?

**Experiment 11.8.** Set up the apparatus shown in Fig. 142(a) and see how long it takes for the weight to fall to the bench. Repeat this experiment with two cardboard blades fitted to slots

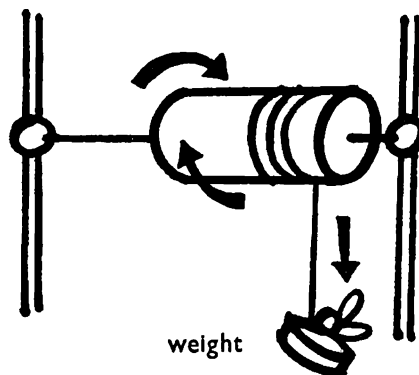


Fig. 142(a)

in the cork 142 (b). Can you suggest why there is a difference in the time of fall?

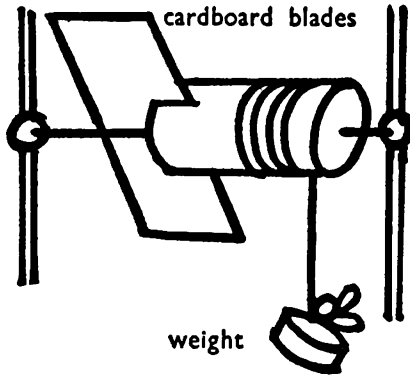


Fig. 142(b)

**Experiment 11.9.** Make a parachute from a handkerchief, some string and a stone (Fig. 143). Does the stone fall more quickly when alone or tied to the parachute? Why? Is the pull of gravity (weight) greater on the stone alone or on the stone plus parachute?

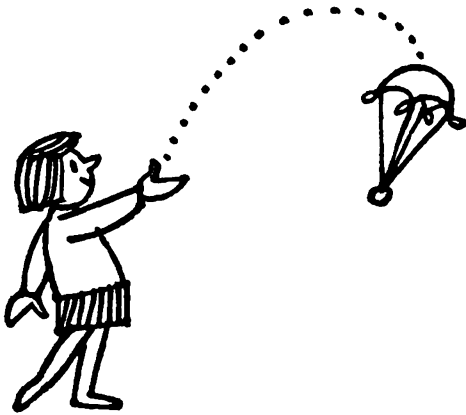


Fig. 143

Aristotle said that heavy things fall more quickly than light things. Galileo is reputed to have dropped a cannon ball and a musket ball from the Leaning Tower of Pisa in order to show that Aristotle was wrong. Galileo claimed that the different balls would reach the ground at practically the same instant. Try the following experiment and say whether you think Aristotle or Galileo was right.

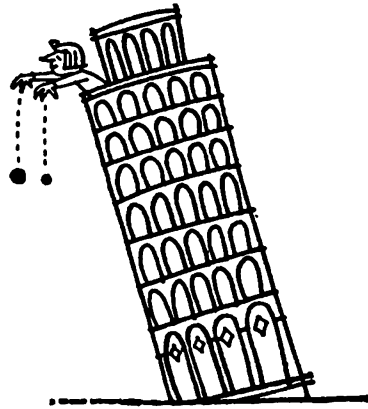


Fig. 144

**Experiment 11.10.** Drop a sheet of paper and a penny at the same time. Which reaches the ground first? Why? Now crumple the paper into a small tight ball and again drop it with the penny. Explain the difference observed. Try dropping a table tennis ball and a golf ball at the same time. Do they strike the floor together?

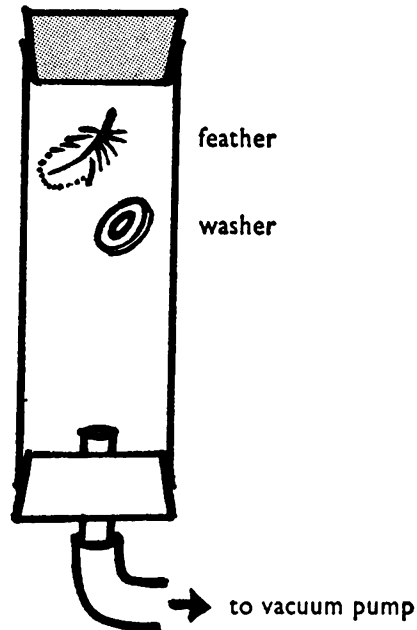


Fig. 145

**Demonstration. 11.11.** Drop a feather and a steel washer together in a glass tube full of air (Fig. 145). Can you think how to use a magnet



to release them both at the same time from the top of the tube?

Which fell more quickly?

Take the air out of the glass tube and repeat the experiment. How do the two objects fall now? Can you explain the difference?

**Experiment 11.12.** Solids, liquids and gases all tend to stop things moving in or over them. They all exert frictional forces. See if you can devise an experiment to find out which of the three exerts the smallest and which the greatest frictional force on a chunk of wood.

*Why is it more difficult to pull a rowing boat on the beach than in the sea? (8) Why do you oil your bicycle? (9) Why does a racing motor cyclist lie over the tank? (10) Why might a satellite 'burn out' when it returns to the Earth's atmosphere? (11)*

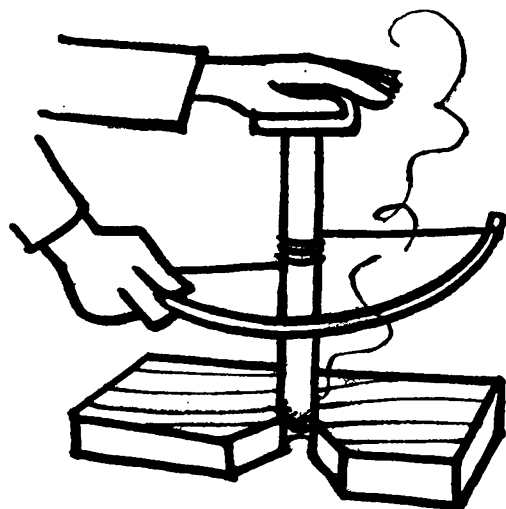


Fig. 146

Before matches were invented, lighting fires used to be a difficult job. American Indians used friction to produce the heat necessary to start a fire (Fig. 146). Gas lighters and cigarette lighters use the heat produced by rubbing flint with steel to ignite coal gas or petrol vapour.

Friction is often considered to be a nuisance. *Why? (12) Life as we know it would, however, be impossible without friction. Describe some of the things you could not do without friction. (13)*

## (b) Action at a distance

*What are the two clues which we look for when detecting a force? (14)*

### (i) Force of gravity

When you throw a ball into the air why does it not disappear into space? Its motion is altered. It slows down because of air resistance. Could air resistance then make it return to the Earth? We call the pull of the Earth gravitational attraction. This is not an explanation, it is merely a name. We do not know why it exists; we just know that it does. We also know that the pull of gravity becomes smaller as we leave the Earth. In a plane flying fifteen miles above the Earth you would weigh about one pound-force less.

**Experiment 11.13.** Squirt a jet of water horizontally from a water pistol or hose pipe. Is its original direction altered?

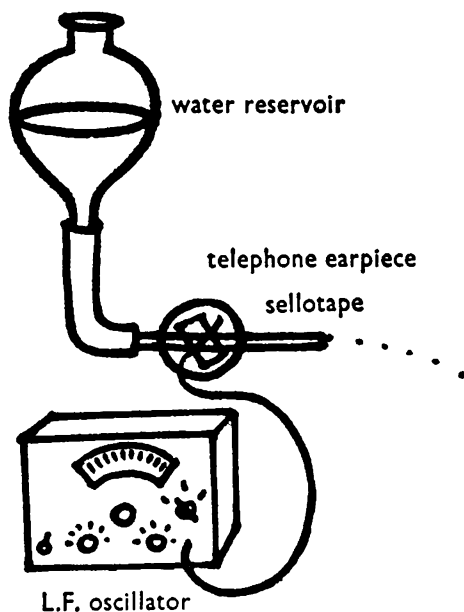


Fig. 147

**Demonstration 11.14.** Here is a fascinating alternative arrangement. Attach a tapered glass tube to the diaphragm of a telephone earpiece using a strip of Sellotape. Supply the tube with water from a reservoir so that the jet of water is projected horizontally. Couple the earphone

to an audio oscillator and illuminate the jet with a stroboscope lamp (Fig. 147). Adjust the frequency of the oscillator and stroboscope until the water drops appear to stand still. Can you make the water appear to go back up into the tube? Alternatively the earphone may be powered from the low-voltage secondary (for example 24 volts) of a mains transformer and a mains-operated neon bulb used instead of the stroboscope.

**Experiment 11.15.** Roll a ball along a bench and let it fly off the end in a horizontal direction. Does it continue in the same direction?

**Experiment 11.16.**

(a) Can the force of gravity alter the shape of a body? Examine a large drop of water on wax or mercury on glass. Try to blow a soap bubble which will lie on a flat surface and examine the shape of the bubble. A solution of sugar and soap makes strong bubbles.

(b) Look at the shape of a car tyre where it touches the road.

**Experiment 11.17.** Does gravity exert the same force on everything? Calibrate a spring balance and then use it to measure the Earth's pull on various objects. What do we call the force which gravity exerts on all objects? In what units is weight measured? A spring, once calibrated, can then be used to measure *any* type of force.

**(ii) Magnetic force**

**Experiment 11.18.** Mount a bar magnet on two watch glasses and study its movement when another magnet or a piece of iron is brought close to it.

Now arrange two magnets to show forces of attraction and repulsion.

What happens to the force of *attraction* as the magnets (i) come closer together, (ii) are moved farther apart? What happens to the force of *repulsion* when the magnets are moved (i) closer together, (ii) farther apart?

**Experiment 11.19.** Sprinkle some polystyrene beads (from Philip Harris) on a sheet of glass or a flat bench top. Now place a small ring magnet (from E. J. Arnold), on the glass and push a second magnet towards it (Fig. 148). Repeat this experiment with one of the magnets

turned upside down and watch the paths of the magnets each time.

Can you arrange this experiment so that (a) motion is started, (b) motion is stopped and

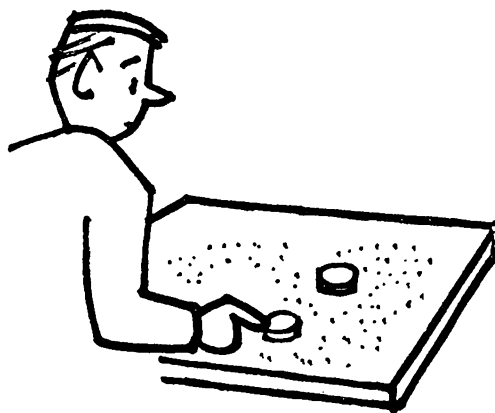


Fig. 148

(c) the direction of the motion is altered by a magnetic force?

The magnets will slide more easily if you glue small cardboard discs on their flat surfaces.

**(iii) Electric force**

**Experiment 11.20.** Devise experiments using strips of polythene rubbed with wool and strips of cellulose acetate rubbed with cotton to investigate electric charges and the forces between them. Can such forces start things moving, slow things down or change direction? How does the distance between the charged rods affect the forces of attraction or repulsion?

We have already learned that all matter is electrical in nature. Each atom contains positive and negative charges. In some materials the electrons (—) are tightly bound to the nucleus (+) and it is difficult to persuade them to leave. Such substances are called **INSULATORS**. A few electrons can be persuaded to leave the atoms of a cellulose acetate rod if it is rubbed with a dry cotton cloth. The result is that the acetate rod, having lost electrons (—), is now positively (+) charged. Work has to be done in moving electric charge (electrons) against the force holding those electrons to the nucleus. The electrons leave the acetate and enter the cotton, which therefore becomes negatively charged.

Are electrons more tightly bound in the atoms of acetate or cotton? (15) If a polythene rod is rubbed with wool it also becomes charged, but this time the electrons come off the wool and join the polythene. With what kind of charge will the polythene be left? (16) How would you test a polythene rod to see if it was charged? (17) What happens if a charged polythene rod is brought close to a charged acetate rod? (18) What happens if two charged polythene rods are brought together? (19) What conclusions have you reached about the force acting between (a) two like and (b) two unlike charges? (20)

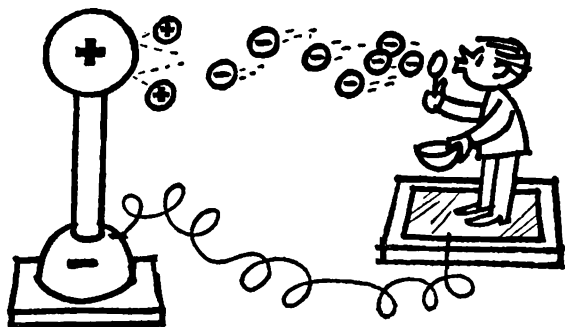


Fig. 149

**Demonstration 11.21.** Blow charged soap bubbles towards the oppositely charged sphere of a Van de Graaff machine and watch what happens before and after they touch (Fig. 149).

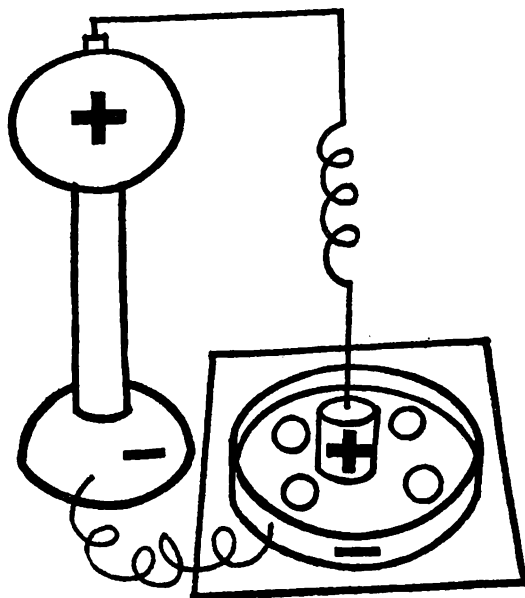


Fig. 150

**Demonstration 11.22.** Make a circular metal band a foot in diameter and lay it on a sheet of glass. Place a calorimeter in the centre and connect it to the dome of a Van de Graaff generator. The band should be connected to the base of the generator (Fig. 150). Paint a few table tennis balls with Aquadag and lay them between the band and the calorimeter. Dry the apparatus thoroughly with a hair drier and switch on the Van de Graaff generator. Explain what happens.

**Experiment 11.23.** (a) Charge a plastic balloon and place it against a smooth wall. Can you explain what happens in terms of forces between electric charges?

(b) Place a charged polythene rod close to a small stream of water coming from a tap. Why is the water direction altered?

### Boy, girl, or twins?

In this section you should try to discover if forces occur singly or in pairs.

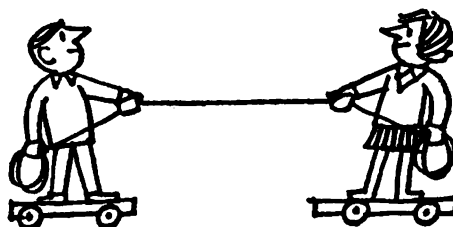


Fig. 151

**Experiment 11.24.** Construct two trolleys or use roller skates for this experiment. A rope connects a boy standing on one trolley and a girl on the other. The original position of the trolleys should be noted. The boy now holds the rope whilst the girl pulls (Fig. 151). Mark the point where they meet. Repeat this experiment with the girl holding and the boy pulling. Finally, try the experiment again with both boy and girl pulling on the rope. Could a dwarf hiding in the middle of this rope tell who was pulling?

**Experiment 11.25.** Attach a spring balance to a hook in a wall and try to find two boys whose maximum pull is approximately equal (Fig. 152). Note the force each is capable of exerting. Now ask the boys to have a tug-of-war with the spring balance. How do you expect the new reading to compare with the

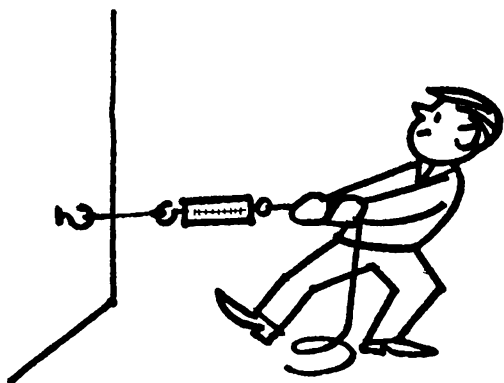


Fig. 152

original reading? Explain the result actually obtained.

**Experiment 11.26.** If four identical spring balances were hung end to end as shown in Fig. 153 (a) and a pull of four pounds-force applied to the lower balance, what would each

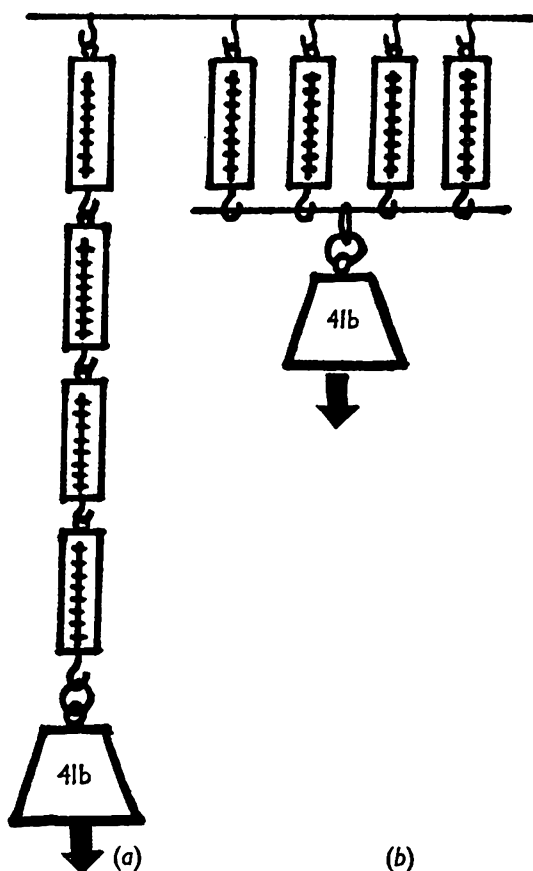


Fig. 153

one read if you ignored the weight of the balances themselves? If the balances were now connected as shown in Fig. 153 (b) what would each one read? Check both of your answers by experiment.

**Experiment 11.27.** Try to knock a nail into a board which is (a) lying on a bench and (b) lying on a heap of hay, a Dunlopillow cushion or some similar material. The force exerted on the nail depends not only on the hammer blow but also on the opposing force which the wood is capable of exerting.

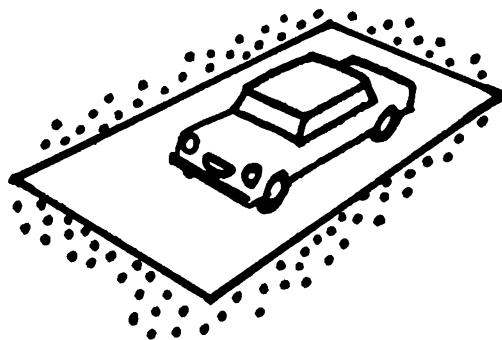


Fig. 154

**Experiment 11.28.** Does a car exert a force on the road or does the road exert a force on the car? Use a friction-driven toy car to help answer this question. Lay a strip of cardboard on some polystyrene beads and place the revving car on the cardboard strip (Fig. 154). Load the car with lead shot and repeat the experiment.

**Experiment 11.29.**

(a) When you jump off the floor are you pushing on the floor or is the floor pushing on you? Jump off a bathroom balance and watch the pointer.

(b) When you jump from the floor on to a table is this a 'world-moving' event? What happens when you jump down again?

(c) When you kick a football do you exert a force on the ball or does it exert a force on your boot? Try kicking a stone of the same size!

(d) When you push against a wall does it push against you? Try this experiment standing on roller skates.

**Experiment 11.30.**

(a) Mount two strong bar magnets on two light trucks as shown in Fig. 155. Bring the north poles together. Holding *B* release *G*.

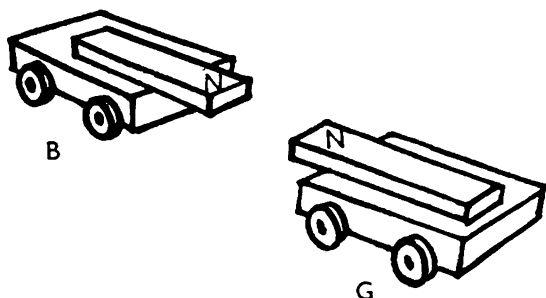


Fig. 155

Now hold *G* and release *B*. Finally release the two trucks together. Does *B* exert a force on *G*, or *G* on *B*?

Plastic toys sometimes have magnets hidden



Fig. 156

inside them. Those can be used to illustrate the same principle. (Magnetic 'Scotties' are available from E. J. Arnold.)

(b) Place a charged polythene rod on an inverted watch glass. Bring a charged cellulose acetate rod towards it. Now interchange the rods and repeat the experiment. Does a polythene rod (—) attract an acetate rod (+) or is it the other way round?

**Action = reaction**

*If you throw a bottle against a wall does the bottle exert a force on the wall or the wall exert a force on the bottle? (21) Is the same true of a cricket ball and a window? (22)* The above experiments (and thought experiments!) have shown that forces do not appear alone. They come in pairs. If you bash your head against a brick wall (action) the wall will, I am afraid, retaliate (reaction). Sir Isaac Newton knew

this hundreds of years ago and said that those two forces, action and reaction, were always equal. One acts in one direction and the other in exactly the opposite direction.

The Earth is attracted to the sun (action) and the sun is equally pulled towards the Earth (reaction). One jet-propelled sea creature moves



Fig. 157

along by squirting out water in one direction (action) and thus it is propelled in the opposite direction (reaction).

*Imagine a boy stranded on some completely frictionless ice. Can you suggest how he could get to the edge of the ice? (23)* It may help you to answer this question if you stand on roller skates or a trolley and throw various objects. *How does a rocket propel itself in space? (24)*

## Muscles, movement and mass

*Why is it more difficult to move a piano than a tea trolley? (25) Can you push a bicycle, a motor bike, a car? You have already discovered one of the reasons why heavier things are more difficult to move. Whenever surfaces are rubbed together forces of adhesion try to hold parts of the surfaces together. If there were no friction could we move a piano as easily as a*

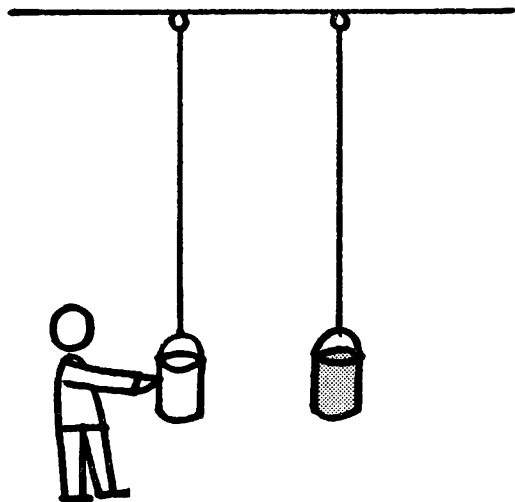


Fig. 158

*chair? (26) It is not possible to get rid of friction completely, but we can reduce it considerably by suspending an object on a long*

*string. What type of friction will now be acting? (27)*

**Experiment 11.31.** Take two large cans or buckets, one filled with sand or water, and the other empty. Suspend them from the highest point available. Try to push each can in turn (Fig. 158). Is the air friction the same in each case? Is there any difference in the push required?

When the cans have again come to rest try to move each one again, this time by pushing each with a gentle force. Can you think of a way of applying an equal small sideways force to each? Do they move off at the same speed when the same small force is applied? Do they speed up?

If you were in a spaceship where the two cans were 'weightless' how do you think you might tell which had the greater mass?

**Experiment 11.32.** When a car driver presses the accelerator pedal what happens to the car? (28) What do you think accelerate means? (29)

Construct a small truck, using pram wheels, and fix a bicycle speedometer to it. The speedometer cable should be attached to the centre of a six-inch wooden disc which runs on one of the wheels. This will give a reading of forty miles per hour at about ten miles per hour! To measure the pull exerted on the truck use a spring balance.

(a) Pull the truck until it moves along slowly

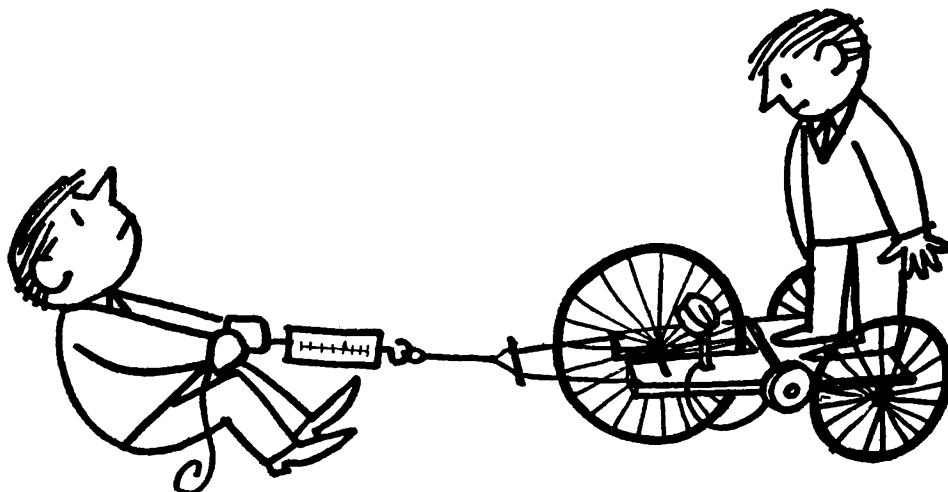


Fig. 159

at a constant speed over a level surface such as the playground. Read the spring balance. What frictional forces are being overcome by the force you are exerting?

(b) Now pull the truck with a *greater* constant force and report what happens to the trolley's speed.

These experiments show us that not only do forces cause things to start moving but that they also make them accelerate provided the force is greater than the force of friction.

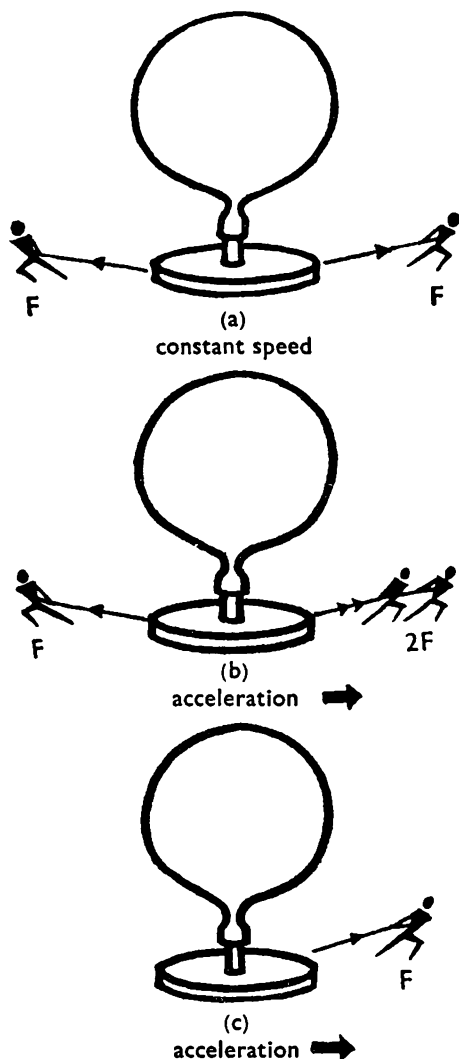


Fig. 160

If two dwarfs apply equal and opposite forces to a balloon puck, which is already moving at a constant speed, it will continue to move at

the same steady speed (Fig. 160 (a)). If two dwarfs were pulling it to the right and only one to the left (Fig. 160 (b)) the puck would accelerate to the right as if it were being pulled to the right by one dwarf alone (Fig. 160 (c)).

*Will a car engine have to exert a greater force to make the car accelerate or to keep it going at a constant speed? (30) Will it use more petrol in travelling a given distance at a steady speed or if it accelerates all the time? (31)*

*Do you think heavy bodies (more mass) are accelerated more or less than light ones (less mass) when a certain force is applied? (32)*

*If a heavy and a light body were going at the same speed, which would need more force to stop it in a given distance? (33) Devise an experiment to test your answer and report the result obtained. (34)*

*Why is a hammer fitted with a heavy head? (35)*

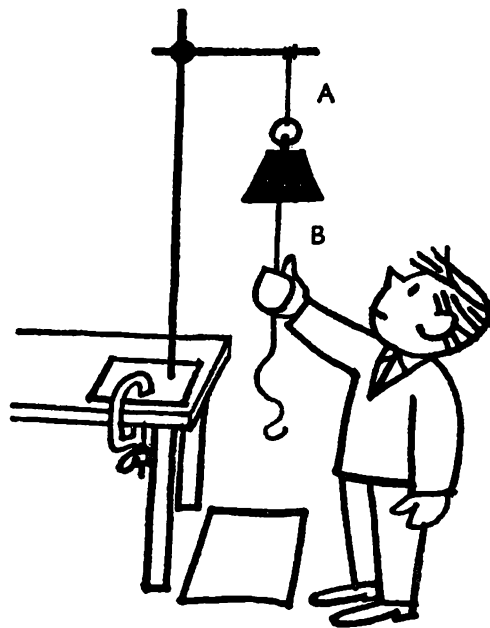


Fig. 161

**Experiment 11.33.** Clamp a retort stand to a bench as shown in Fig. 161. Now tie a four-pound 'weight' to a retort stand clamp using thread A as shown. Tie a similar thread B to the bottom of the 'weight'. If you exert a steady force to the lower end of thread B, will the tension (force) be greater in thread A or B?

Why? Exert a steady pull until one of the threads breaks.

Now repeat this experiment, but this time give thread *B* a sudden tug. Which thread breaks? Why?



Fig. 162

When a body is stationary, a force is needed to start it moving. If the body is moving, another force is required to stop it. This 'dislike' of change is called **INERTIA**. The greater the mass of a body the greater is its inertia. In fact mass is a measure of inertia.

**Experiment 11.34.** Place a card on a wide-necked bottle and lay a threepenny piece on top of it (Fig. 162). Now give the card a sharp knock so that it is whipped off the bottle. Why does the coin fall into the bottle?

*If you are standing on a bus when it brakes suddenly, what happens and why? (36) Why are many cars now fitted with safety belts? (37) If a lorry were to bump into a stationary car standing on a perfectly frictionless surface would any damage be done? (38)*

*Would a force be needed to accelerate a body in a spaceship in which things were 'weightless'? (39)*



# Turn. Twist. Topple

## CHAPTER 12

### Turn

If you have to remove the front wheel from a bicycle you will, or should, find that it is impossible to slacken the nut with your fingers. You cannot exert a great enough turning effect. *If you were using the spanner illustrated in Fig. 163 would you hold it at A, B or C? (1) Why? (2)*

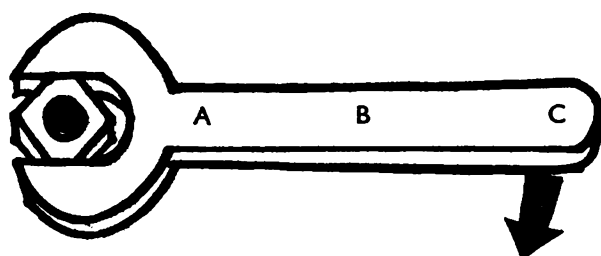


Fig. 163

A penny may be used to open a coffee tin. *Draw a tin being opened in this way, and mark the points where forces are acting. (3) Would you prefer to use a penny or a screwdriver to open a paint tin? (4) Why? (5)*

*Would it be just as easy to open a door if the handle were fitted close to the hinged edge? (6) Explain your answer. (7)*

**Experiment 12.1.** A metre stick has three holes drilled in it at the 50-cm mark (X, Y, Z). Balance the stick on a knitting needle so that it always returns to the horizontal position with the centimetre scale uppermost (Fig. 164). Which hole must be used? If the stick won't balance exactly use a paper clip or crocodile clip to balance it.

Now stick a piece of white adhesive tape along the centre of the metre stick and mark it off every 10 cm, starting from the holes in the middle. We will use this scale for the rest of the experiment. Replace the stick on the needle

and rebalance it by adjusting the clip if necessary.

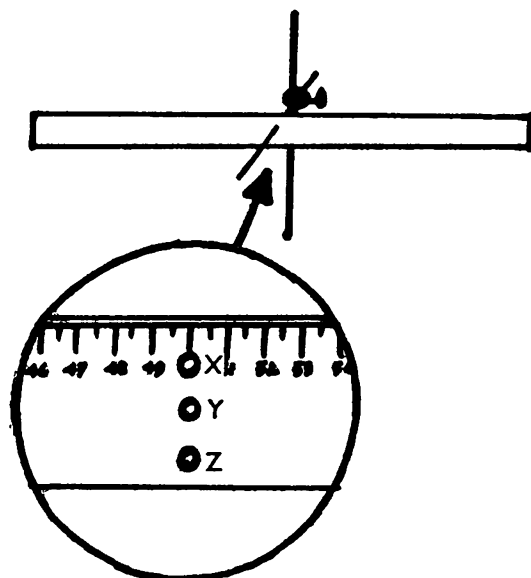


Fig. 164

Make a loop of thread which will slide easily over the metre stick and attach a 20-g 'weight' to it. Attach the 'weight' to the metre stick so

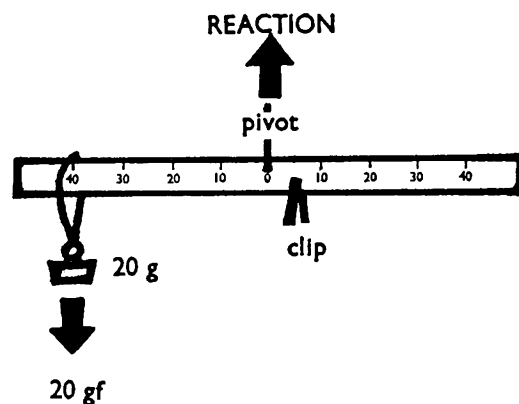
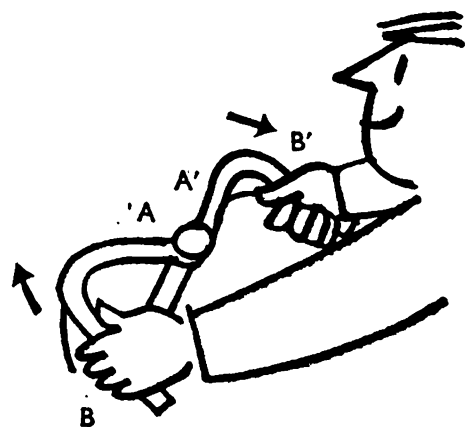


Fig. 165

that it is 40 cm from the pivot (Fig. 165). Balance the metre stick again by hanging another 20-g 'weight' on the opposite side of the pivot. Note how far it is from the centre. Leave the first 20-g 'weight' on the 40-cm mark and again balance the stick with a 'weight' of 40, then 80, and then 160 g hung on the other side. Note carefully how far away from the pivot the 'weights' are hung each time. Make a table of your results as follows.



## Twist

Sometimes it is more convenient for someone to exert a pair of forces to cause rotation. To turn a water tap, for example, a force is exerted at each end.

When steering a car or a bicycle two equal forces are applied in opposite directions (Fig. 166). *Would you have greater control of a bicycle by holding the handlebars at AA' or BB'? (12) Why are wing nuts not used as often*

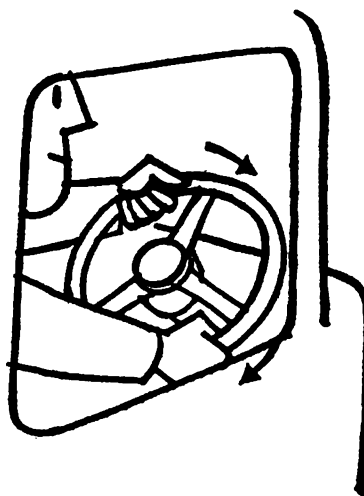


Fig. 166

The same turning effect is obtained by

|            |       |                |
|------------|-------|----------------|
| (a) 20 gf  | 40 cm | from the pivot |
| (b) 40 gf  | cm    | „ „ „          |
| (c) 80 gf  | cm    | „ „ „          |
| (d) 160 gf | cm    | „ „ „          |

Can you see any connection between the force and the distance from the pivot? Apart from the weights pulling on the metre stick what other forces act on it?

*A seesaw balances with no one on it. If a boy weighing eight stones sits three feet from the pivot where must a girl weighing four stones sit so that the seesaw balances? (8) Where would a girl weighing six stones have to sit to counter-balance the boy? (9)*

*If you had to carry a spade by the end of the shaft would you prefer to hold the spade vertically or horizontally? (10) Why? (11)*

*as ordinary hexagonal nuts on bicycles and cars? (13)*

A twisting action with two equal and parallel

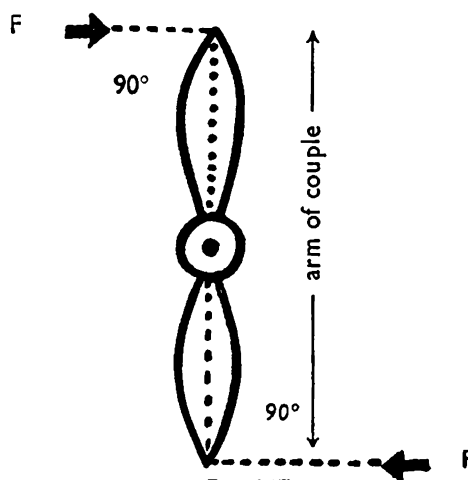


Fig. 167

forces is called a couple. The distance between the forces is called the arm of the couple. The arm is measured at right angles to the direction at which the forces act (Fig. 167).

## Topple

*If you were carrying a heavy hammer where would you hold it? (14) What part of a ladder would you rest on your shoulder in order to carry it most comfortably? (15)* Although gravity pulls down on every molecule in the ladder it is sometimes convenient to think of it as pulling downwards, with a force equal to the total weight of all the molecules, at one point. This point is called the *centre of gravity*. It is almost as though the rest of the ladder were weightless and the middle rung were made of lead! The centre of this middle rung is then called the centre of gravity. If you hold the ladder at that point it will balance.



Fig. 168

**Experiment 12.2.** Tie a bob on to the end of a string and hold the other end (Fig. 168). Such an arrangement is called a plumb line. As the string always comes to rest vertically can you think of some uses for a plumb line?

Notice that the bob always comes to rest vertically *below* the point of suspension (finger).

*As the centre of gravity of a body behaves in the same way as the bob on the plumb line, where will the centre of gravity be when a body is freely suspended? (16)*

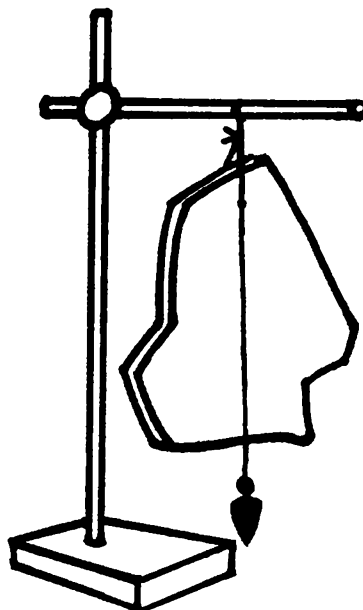


Fig. 169

### Experiment 12.3.

(a) Try to find the centre of gravity of a sheet of cardboard using a plumb line.

Hang the cardboard sheet from a retort stand. Where will the centre of gravity of the sheet come to rest with respect to the point of suspension *A*? Now suspend a plumb line from *A* and draw a line on the sheet showing where the plumb line touches it (Fig. 169). The centre of gravity of the cardboard must be somewhere on this line. At present we do not know where. Can you think of a way of drawing another line on the cardboard on which the centre of gravity will lie? If you can do this the centre of gravity must be at the point where the lines cross. Why?

Having found the centre of gravity, how would you make sure that this is the balance point for the cardboard sheet?

(b) Stick a lump of Plasticine on one edge of

the cardboard sheet and find the *new* centre of gravity using the same method as before. Where does the new centre of gravity lie in relation to the original centre of gravity and the Plasticine?

### Equilibrium

If a body is standing or is suspended in such a way that it stays put, that is, it doesn't move unless it is touched, the body is said to be in equilibrium. A picture hanging on the wall, a teacup standing on a saucer or a penny balanced on its edge are all in equilibrium.

When a body such as the cardboard sheet is supported at a point vertically above the centre of gravity the body is said to be in stable equilibrium. That is, if you push it one way or another it will always return to its original position. *When you hold a suitcase does the centre of gravity of the case plus the contents lie above or below the carrying handle? (17) Is the suitcase in stable equilibrium? (18)*

*If you had to lift your bicycle over a tree, which had fallen across the road, would you lift it by the front wheel, the handlebars, the cross bar, or the rear mudguard? (19) Why? (20) Describe how you could find the centre of gravity of your bicycle. (21) Remember that the centre of gravity is the point through which the weight may be considered to act.*

**Experiment 12.4.** It is not easy to find the centre of gravity of an irregular solid body, but you can find the centre of gravity of some objects, using a little ingenuity, some string, and some Sellotape. Try to find the centre of gravity of at least one of the following: a ring, a stool, a chair, a tripod stand, a waste-paper basket, a retort stand, a setsquare or a bird cage. In each case you should suspend the object so that it is in stable equilibrium.

**Experiment 12.5.** Take a metre stick with three holes drilled in the middle as shown. The centre hole (Y) should be at the centre of gravity. Support the stick on a knitting needle through the hole marked X (Fig. 170 (a)). What happens when you tilt the stick? Is it in stable equilibrium? Try to balance the stick with the needle through hole Z (Fig. 170 (b)). Can it be balanced with X above Z? What happens if the stick is slightly tilted? In the first case

(needle through X) did the centre of gravity of the stick rise or fall when the stick was tilted? In the second case (needle at Z) did the

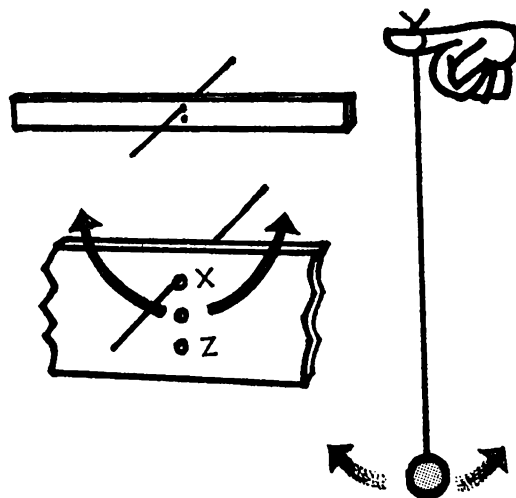


Fig. 170(a). Stable equilibrium

centre of gravity rise or fall when the stick was tilted?

When the centre of gravity rises, gravity tries to pull it back to its original position and so we

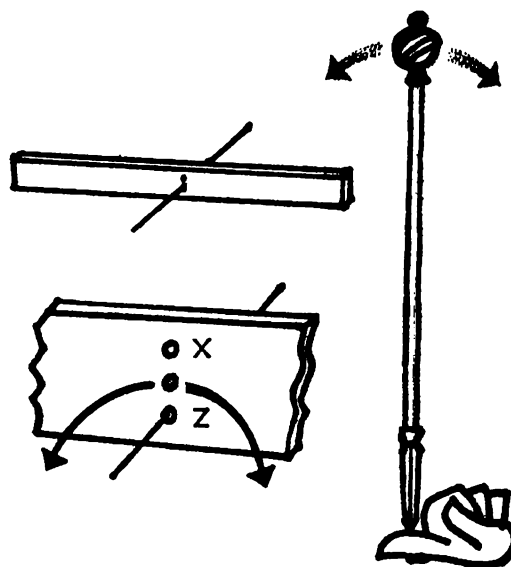


Fig. 170(b). Unstable equilibrium

have stable equilibrium. When the centre of gravity falls, gravity tries to make it fall still farther and the body is in unstable equilibrium.

A pendulum is in stable equilibrium, but if you try to balance a poker on your finger you will find it is unstable.

If it were possible to support the metre stick exactly at its centre of gravity would the centre of gravity rise or fall when the stick was tilted? (22) In practice it is difficult to arrange that the stick is supported exactly at its centre of gravity. Nevertheless you should examine the effect of supporting the stick with the needle in hole Y. If the stick can be rotated to any position and stays there, it is said to be in neutral equilibrium. In Experiment 12.4. you found the centre of gravity of a cardboard sheet (lamina). Stick a pin through the centre of gravity to support the lamina. Is it in neutral equilibrium? (23)

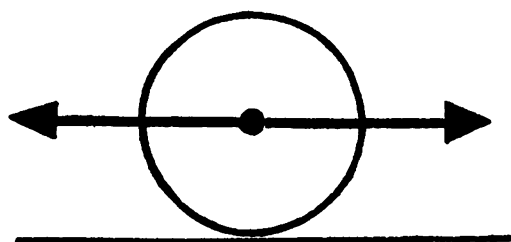


Fig. 171. Neutral equilibrium

A perfectly round ball on a perfectly smooth level surface is in *neutral equilibrium* (Fig. 171). If the ball is moved its centre of gravity remains at exactly the same height above the surface. If you roll a ball along a rough road, where does it normally come to rest? (24) Is it in stable or unstable equilibrium then? (25)

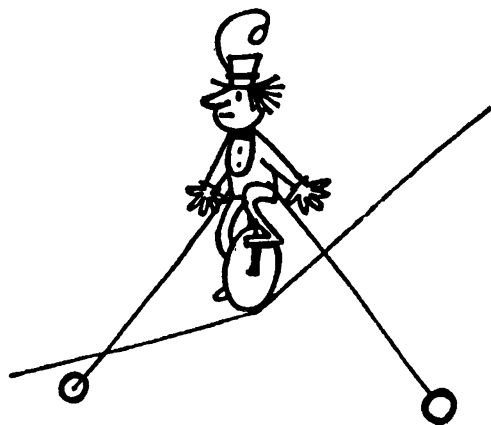


Fig. 172

Is a tightrope walker in stable or unstable equilibrium? (26) Why does he often carry a long pole? (27) Try to balance a bottle on a tight string using an umbrella with a J-shaped handle.

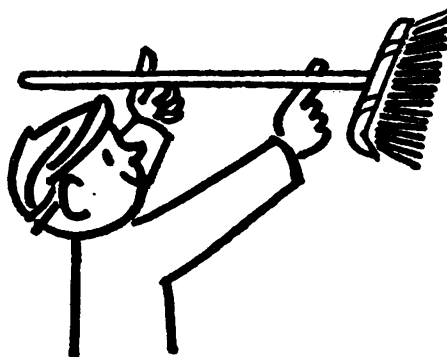


Fig. 173

**Experiment 12.6.** Rest a broom on two fingers as shown (Fig. 173). Slowly bring your fingers together. At what part of the broom do your fingers meet?

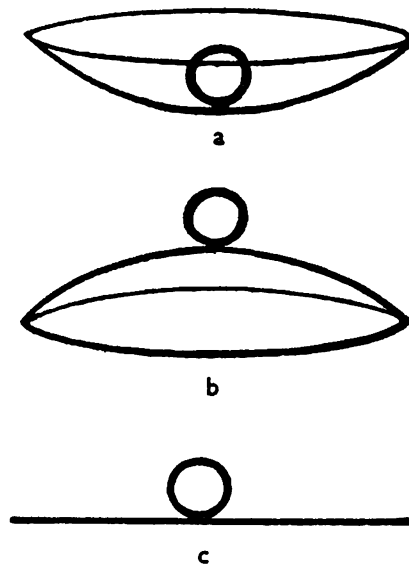


Fig. 174

**Experiment 12.7.** Place a ball-bearing in a watch glass as shown in Fig. 174 (a). If you move the ball does its centre of gravity rise or fall? When released does it return to its original position? Is it in stable or unstable equilibrium in the position illustrated? If it



Fig. 175

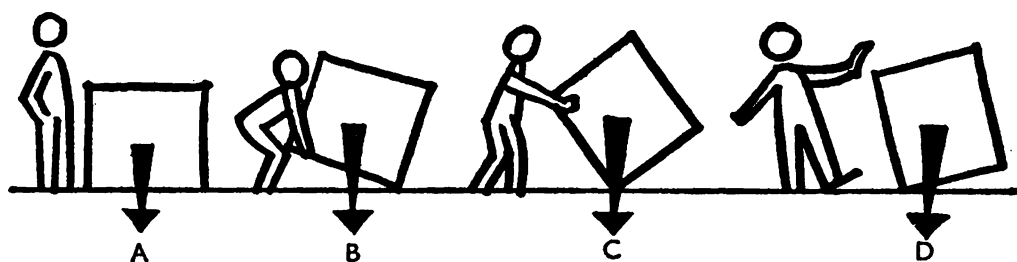


Fig. 176

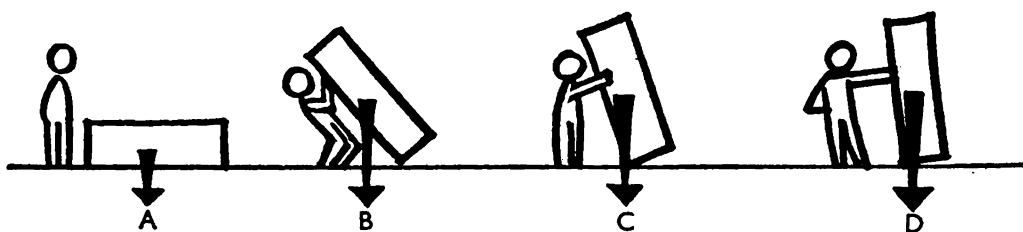


Fig. 177

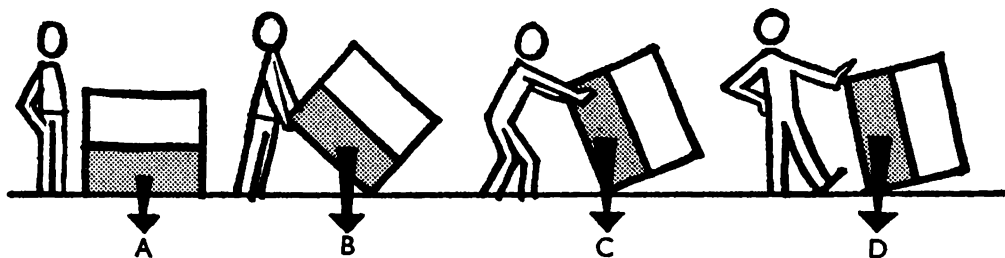


Fig. 178

were possible to rest the ball on an inverted watch glass as shown in Fig. 174(b) would it be in stable or unstable equilibrium? What happens to its centre of gravity when it moves slightly off the crest of the watch glass?

If the ball-bearing is laid on a flat level plate of glass (Fig. 174(c)) what happens to the height of the centre of gravity when the ball is moved slightly?

### Stability

Practically everything we use in everyday life is in stable equilibrium. You can amuse and baffle your friends by constructing gadgets which look as though they were unstable but in fact are stable. *Can you explain why the arrangements shown in Fig. 175 are stable?* (28)

#### Experiment 12.8.

(a) Take a wooden cube and tilt it until it topples over. Notice how much it is tilted before it topples. Is the block in stable equilibrium at *A*, *B*, *C* or *D*? (Fig. 176). Is it in unstable equilibrium in any of these positions? In which positions is the block not in equilibrium at all?

(b) Repeat the above experiment with a rectangular block of wood. Do you have to tilt this block more or less than the cube before

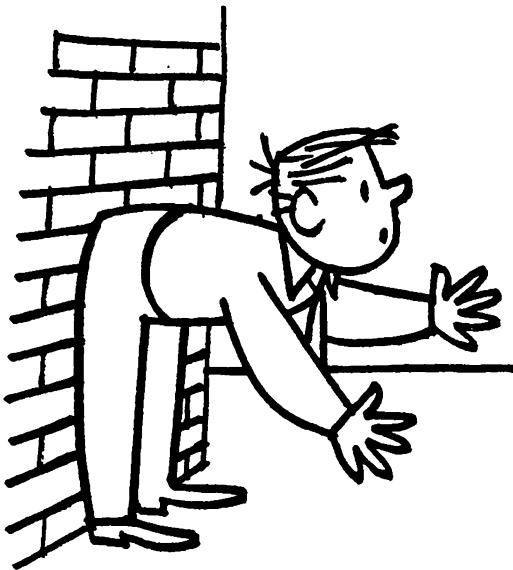


Fig. 179

it topples? Do any of the positions shown in Fig. 177 represent stable or unstable equilibrium? Do you think this block in position *A* is more stable than the cube?

(c) Take an empty cardboard box and glue a slab of wood in the base. Will it topple over when in position *A*, *B*, *C* or *D*? (Fig. 178). Repeat this experiment with the box upside down and draw diagrams showing when it will topple.

*From the experiments you have done can you say when a body will topple?* (29)

**Experiment 12.9.** Stand with your back to a wall and your heels touching the wall. Now keep your knees straight and touch your toes. Why is this difficult?

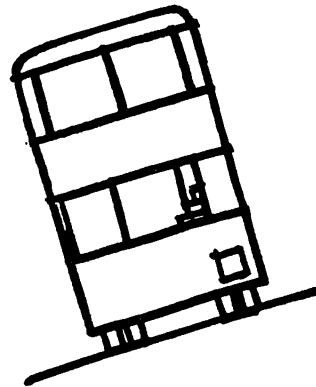


Fig. 180

A double-decker bus does not topple easily because its centre of gravity is low. *How is this made possible?* (30) *Why are passengers not allowed to stand on the top deck?* (31)

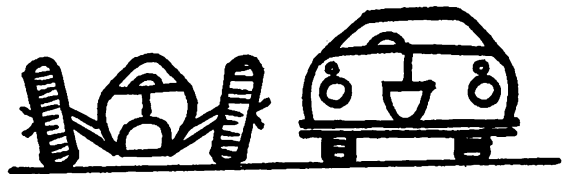


Fig. 181

*Which of the two racing cars in Fig. 181 do you think would be more easily overturned when standing on a slope?* (32) *Draw a diagram showing how far you think they could be tilted before toppling.* (33)

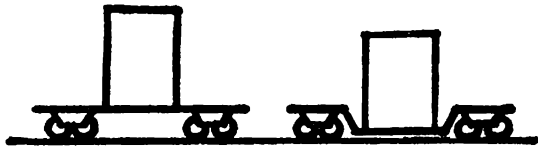


Fig. 182

Which type of truck illustrated in Fig. 182 will be better for carrying heavy loads? (34) Why? (35)

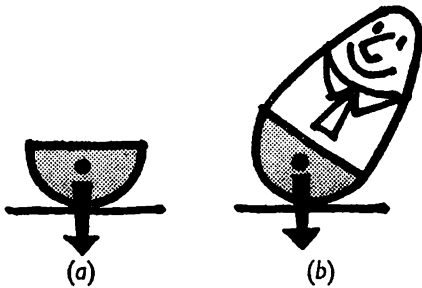


Fig. 183

**Experiment 12.10.** Take a solid ball of rubber or wood and saw it through the middle. Lay

one of the hemispheres on its curved surface (Fig. 183 (a)). What happens if this hemisphere is pushed over slightly in any direction? Why? Now glue a paper figure to the hemisphere and once it is dry try to push it over (Fig. 183 (b)).



Fig. 184

Why does this fellow not stay down when you push him?



# Work—work—work

## CHAPTER 13

### Energy

Were all advertisements true, then X breakfast cereal, Y fruit juice and Z pills would give you all the energy you require! What do we mean when we say someone has 'lots of energy'? We mean that he can do lots of work. This is exactly what we mean in physics too. Work is done when one form of energy changes to another. As our bodies are continually changing energy from one kind (chemical) to another (heat), we are working even when we are sleeping. This is not, however, the kind of work you will be encouraged to perform in the laboratory!

Energy is one of the most important things with which physics is concerned. Consider the first few minutes of an average day. You are awakened by an alarm clock which has energy stored in a coiled spring. As it unwinds, this stored energy—*potential energy*—turns the wheels of the clock and rings the bell. *Mechanical energy* is being changed to *sound energy*. You jump up (eventually) and the energy stored in your body—*chemical energy*—is changed into energy of movement—*kinetic energy*—as you hurriedly get dressed. If your breakfast is cooked by gas, the burning of the gas changes *chemical energy* into *heat energy*. If an electric cooker is being used *electrical energy* is changed into *heat energy*. In summer you see to eat your breakfast by the sun's rays—*radiant* or *light energy*—and in winter *electrical energy* is changed to *radiant energy* to enable you to see. Perhaps the electricity was generated by *nuclear energy* or by a coal-burning steam turbine. In the latter case *chemical energy* (coal) is changed to *heat energy* (steam), then to *mechanical energy* (turbine), then to *electrical energy* (generator) and then to *radiant energy* (light). *How many types of energy have already been*

*mentioned? (1) How many kinds of energy can you name which are used in bringing you the eight o'clock news? (2)*

Energy is forever being changed from one kind to another. The study of all forms of energy and of the changes from one form to another is one of the major parts of physics. You cannot make energy or cause it to disappear; you can only change it into a different form. Scientists call this fact the *conservation of energy* and textbooks usually say, 'Energy cannot be created or destroyed'.

**Experiment 13.1.** Connect two *low-resistance* headphones by a long length of flex. You can speak from one room to another with this apparatus used as a telephone. State all the energy changes that take place.

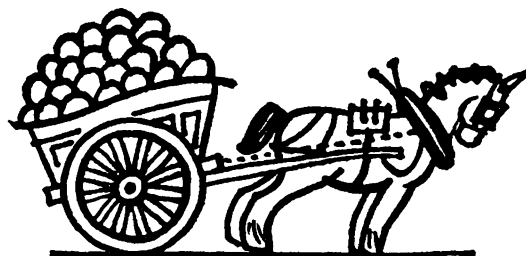


Fig. 185

### Work

If a horse pulls a cart with a steady force of 500 lbf so that the cart moves 10 ft, the horse does work in overcoming friction.

If the cart moves 10 ft, the horse does some work. If the cart moves 20 ft the horse does twice as much work; if 30 ft, three times as much work, and so on. If the horse were pulling two carts and, in so doing, exerting twice the force, that is 1,000 lbf, the horse would do twice as much work as it did in moving one cart the

same distance. In each of the above cases work is done at the expense of some of the horse's energy which, in turn, came from the energy in the food the horse had eaten.

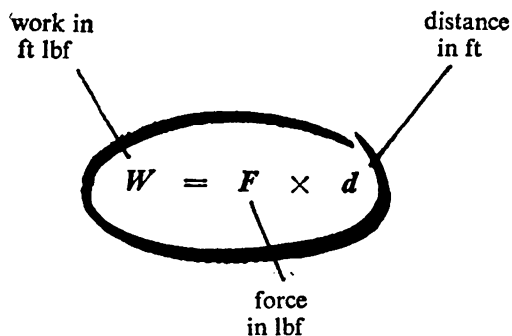
Suppose that when a force of  $F$  lbf moves a body  $d$  ft the work done is  $W$  units. Then if the force is  $2F$  lbf, the work done will be  $2W$  units, etc.

| Force (lbf) | Distance (ft) | Work (ft lbf) |
|-------------|---------------|---------------|
| $F$         | $d$           | $W$           |
| $2F$        | $d$           | $2W$          |
| $3F$        | $d$           | $3W$          |
| $3F$        | $2d$          | $6W$          |
| $3F$        | $3d$          | $9W$          |

This gives us a simple method of indicating the amount of work done. We multiply the force exerted by the distance moved and use this as a measure of the work done.

Work done = Force  $\times$  distance

As we have measured distance in feet and force in pounds-force, work done will be measured in feet multiplied by pounds-force, that is foot pounds-force (ft lbf). You will still often hear this referred to as *foot-pounds*, but we will use *foot pounds-force* to remind ourselves that we are dealing with a unit of force rather than mass.



A man pushes a barrow with a force of 40 lbf and moves it 100 ft. *How much work has been done by the man?* (3) *Where does this energy come from?* (4) *How much work would the man do if he pushed it* (a) 200 ft? (b) 300 ft? (5)

If you were to push the side of a truck and continue pushing until you were exhausted without having moved it you would not have done any mechanical work (Fig. 186). True,

chemical energy would have changed to heat energy and in this sense work would have been done, but you would not have done mechanical work. Even if the truck had been on a slight

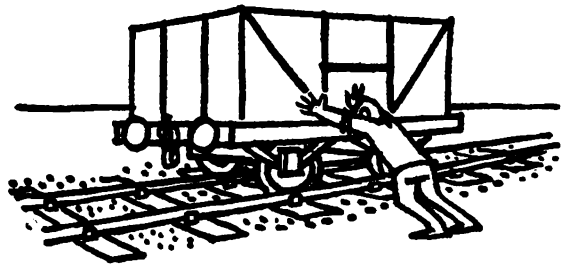


Fig. 186

hill so that as you pushed it sideways it ran down the hill, *you* would not have been doing work on the truck. The work would have been done by gravity.

The work which you do on the truck is measured by the product of the force you exert and the distance the truck moves *in the direction in which you are pushing it*.

### Movement without work

We have seen that forces can act without doing work. On the other hand bodies can keep moving without energy being transformed; that is, without work being done. Satellites spin round the earth and, provided there are no frictional forces acting on them to cause them to lose energy, they continue moving without work being done on them.

### Lifting

#### Experiment 13.2.

(a) Lift a 10-lb box using a spring balance (Fig. 187 (a)). How much force do you exert? Is the box moving in the direction in which you exert the force? Can you exert *more* than 10 lbf in lifting the box? If you do what happens to the box? If you raise the box slowly and steadily what force do you exert? If you raise the box 1 ft how much work have you done? Work has been done against gravity and the energy stored is called potential energy. Can the energy now in storage be used to move the box again?

(b) Now place the 10-lb box on a trolley and see what force you have to exert to lift both box and trolley (Fig. 187 (b)). How much work have you done in lifting both of them one foot?

(c) How much force do you have to exert to pull the box and trolley slowly along a level floor? (Fig. 187 (c)). How much work have you done in moving it 1 ft along the floor? Into what form has the energy been transformed now? Can the energy be used again to move the box?

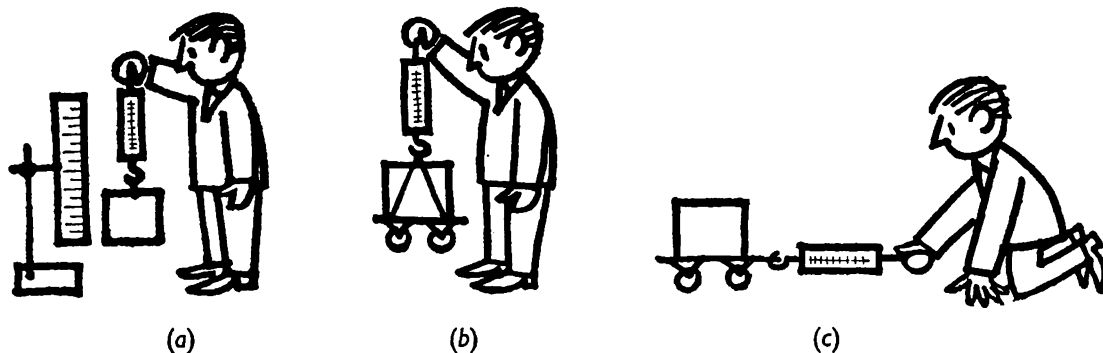


Fig. 187

(d) Place the box on the floor and see how much work you have to do to pull it 1 ft along the floor? Is this more or less than the work done in pulling both trolley and box 1 ft along the floor? Explain the difference.

## Units

Suppose that two boys are asked to lift boxes. One boy lifts a 50-lb box 2 ft. He has done  $50 \times 2 = 100$  ft lbf of work. The other boy raises an 80-lb box 2 ft. He has done 160 ft lbf of work. The boxes now have more energy than they had before. They have potential energy. As the work done by the boys is exactly equal to the gain in potential energy of the boxes we use the same units (ft lbf) for work and energy. We could, in fact, use ft lbf to measure every form of energy.

Just as you might use centimetres when measuring the length of your tongue, miles to express the distance from London to Aberdeen and light years to estimate the distance to a star, so we tend to use different units for energy

in different forms. It is simply a matter of doing sums to change from one kind of energy unit to another just as you can change inches to centimetres by multiplying by 2.54.

Here are some of the units in which energy (or work) is measured.

|                   |                                |
|-------------------|--------------------------------|
| Mechanical energy | foot pounds force (ft lbf)     |
|                   | centimetre grams force (cm gf) |
|                   | ergs                           |
|                   | joules                         |

|                   |                                        |
|-------------------|----------------------------------------|
| Heat energy       | calories                               |
|                   | joules                                 |
|                   | British Thermal Units                  |
|                   | therms                                 |
| Electrical energy | joules                                 |
|                   | Kilowatt hours (Board of Trade 'unit') |

You will notice that there is only one unit that is used in all those forms of energy. It is the joule. You will be hearing much more about this unit later, as it is now the unit on which all the others are based. For the time being we will use only foot pounds-force (ft lbf).

## A day's work

If a coalman were to deliver 200 bags of coal in a day and if, on the average, each bag had to be carried up 10 ft of stairs we could estimate the work he does. Of course he has to raise his own weight 10 ft every time he carries the coals, and so we must take this into consideration as well. Estimating the total weight of the coalman

plus one bag of coals as 250 lbf, the work done would be

$$250 \times 10 = 2,500 \text{ ft lbf per bag of coal}$$

The total day's work would then be

$$200 \times 2,500 = 500,000 \text{ ft lbf}$$

If all this energy had been changed into heat, it would just about boil dry a cupful of water! If this energy had been obtained from the electricity supply it would have cost about a farthing! You can see why it is not always cheapest to 'do it yourself'.

## Machines

Machines are energy transformers. They do not all change one form of energy into another as does, for example, a washing machine. A machine can change mechanical energy involving a small force into mechanical energy involving a large force. A lever is probably the simplest example of such a 'machine'. A tyre lever enables you to exert a greater force than you are capable of doing with your fingers.

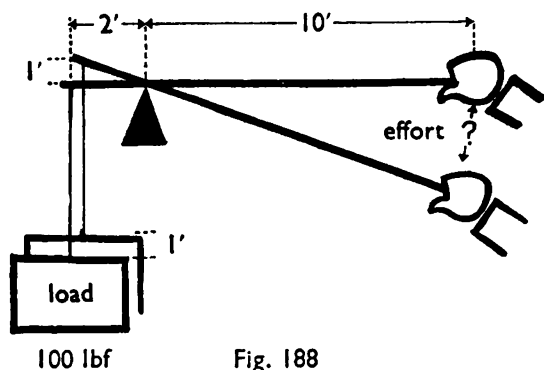


Fig. 188

Does a machine give us something for nothing? Consider Fig. 188. We will ignore the weight of the lever itself for the time being. A load of 100 lbf is to be lifted by applying an effort as shown. *If the load is raised 1 ft how much potential energy will it have gained?* (6) *As the effort is five times farther from the fulcrum than the load, how far will the effort have to move when the load is raised 1 ft?* (7)

For centuries man tried to invent a device which would continue going by itself once

started. *What are such devices called?* (8) We now know that you cannot get more energy from a machine than you put in. If we get  $1 \text{ ft} \times 100 \text{ lbf} = 100 \text{ ft lbf}$  of energy from this machine we must put into the machine at least 100 ft lbf. As the effort has to move through 5 ft the force applied must be  $\frac{100}{5} = 20 \text{ lbf}$ . An effort (force) of 20 lbf can raise a load (another force) of 100 lbf, but—and this is very important—the energy we get out is never greater than the energy we put in. In practice the energy we get out is always slightly less than the energy we put in. *Why?* (9)

## Mechanical advantage

If, for the moment, we assume that there is no friction at the fulcrum of the machine illustrated above (Fig. 188) then the load ( $L$ ) of 100 lbf can be raised by an effort ( $E$ ) of 20 lbf. We have been able to exert  $\frac{100}{20} = 5$  times the original force.

If the load had been 300 lbf the effort would have been 60 lbf. Again we obtain a force five times greater than the force we apply. The machine will 'multiply the force' by five. This is called the mechanical advantage ( $MA$ ) of the machine. It can be calculated by dividing the load by the effort; that is, we find out how many times the load is bigger than the effort.

$$\text{Mechanical Advantage} = \frac{\text{Load}}{\text{Effort}}$$

## Velocity ratio

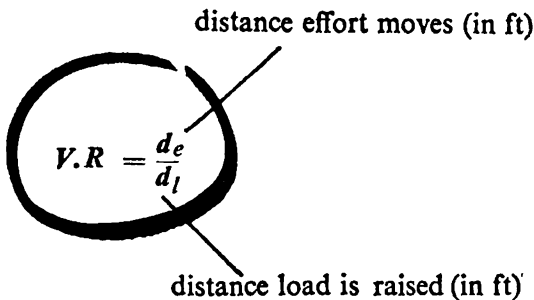
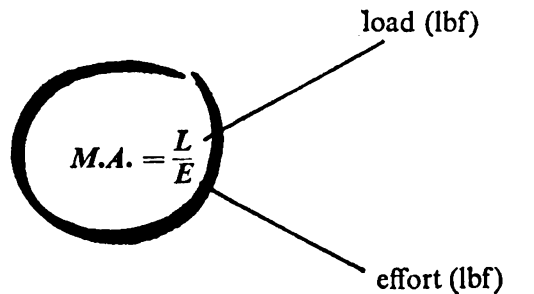
If your hand (effort) pushes the lever down 5 ft in one second the effort is moving at a speed of 5 ft/s (Fig. 188). In the same time (one second) the load has been raised 1 ft. The load is therefore moving more slowly than the effort. The load moves at only 1 ft/s.

The speed of the effort is therefore five times greater than the speed of the load. This can be expressed as a 'ratio', that is, one speed divided by the other. The speed ratio is then  $\frac{5}{1} = 5$ . This ratio is sometimes referred to as the velocity ratio ( $V.R.$ ). As the speeds (velocities) of both effort and load are being considered during the *same* interval of time (one second in the above case) we can find the velocity ratio

by measuring the distance through which each force acts.

$$\text{Velocity ratio} = \frac{\text{Distance effort moves}}{\text{Distance load is raised in the same time}}$$

Mechanical advantage is really a force ratio and velocity ratio, is, in effect, a distance ratio.



In the above example both M.A. and V.R. are equal to 5. This is because we have ignored any friction at the fulcrum.

Ignoring friction at the pivot and the weight of the lever, what forces would be required to lift the 20-lb load shown in Fig. 189? (10) What is the mechanical advantage of this lever? (11) What is its velocity ratio? (12)

Let us continue for the moment to ignore the weight of the lever but now take friction into consideration. Will friction at the pivot affect the mechanical advantage or the velocity ratio of the machine? (13) Does the M.A. or V.R. become more or less because of friction? (14) If the lever was a solid bar with its centre of gravity in the middle would this affect the M.A. or V.R.? (15) If so, in what way? (16)

How much potential energy does the load in Fig. 189 gain if it is raised 6 in? (17) What work is done by the effort in raising the load 6 in if the mechanical advantage of the machine is 4? (18)

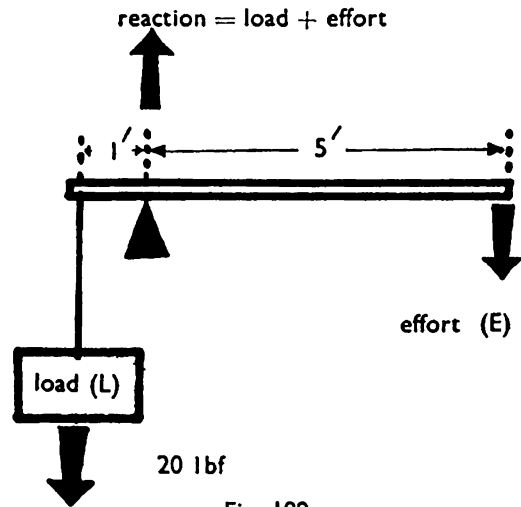


Fig. 189

The potential energy gained by the load is called the *output* and the work done by the effort is called the *input*. To find the input and output of mechanical energy multiply the force by the distance moved in each case. Will the input always be greater than the output in a real machine? (19)

Devise an experiment to find the M.A. and V.R. of a bicycle. (20)

### Wheel and axle

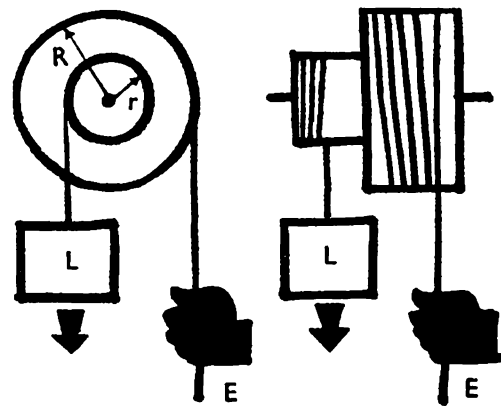
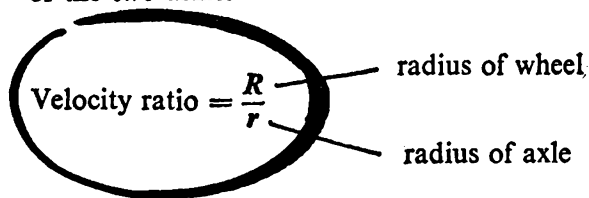


Fig. 190

The wheel and axle is a kind of continuous lever (Fig. 190). One arm of the lever ( $r$ ) is the radius of the smaller drum (or axle) and the

other arm of the lever ( $R$ ) is the radius of the large drum (or wheel). The pivot is at the centre. As in the case of the lever the V.R. is the ratio of the two arms.



*Does the V.R. of a wheel and axle vary with the load raised? (21)*

**Experiment 13.3.** Construct a wheel and axle from an empty cotton reel and a piece of dowelling. Measure the diameters of the two drums and calculate the velocity ratio. Using various loads find the effort which, in each case, will just raise the load. Write down your results in a table and calculate the mechanical advantage of the machine for each result. Now draw a graph showing how the mechanical advantage varies with the load.

| Load | Effort | M.A. |
|------|--------|------|
|      |        |      |
|      |        |      |
|      |        |      |

M.A.

M.A./Load for a Wheel and Axle

Load

## Pulleys

A few simple pulley systems are illustrated in Fig. 191. *Can you work out the velocity ratio for each? (22)*

You can best find the velocity ratio in each case by imagining that the load has been lifted 1 ft as shown in Fig. 191 (c) and then working out what length of rope has to be pulled in by the effort to take up the slack.

**Experiment 13.4.** Fix up a block-and-tackle system and find the effort required to raise various loads. Calculate the mechanical advantage in each case. How does the mechanical advantage vary with the load? Is the mechanical advantage always greater or always less than the velocity ratio? Why?

## Players and reserves

There are so many different types of energy that it may be helpful to think of them under two headings: players and reserves. Players are forever tearing around the field, and we call their energy the energy of movement or *kinetic energy*. The reserves, on the other hand, are fully trained and waiting to be given the chance to move off. They are potential players. They have plenty of energy stored up and are willing to release it the minute they are given the opportunity. We say that they have *potential energy*.

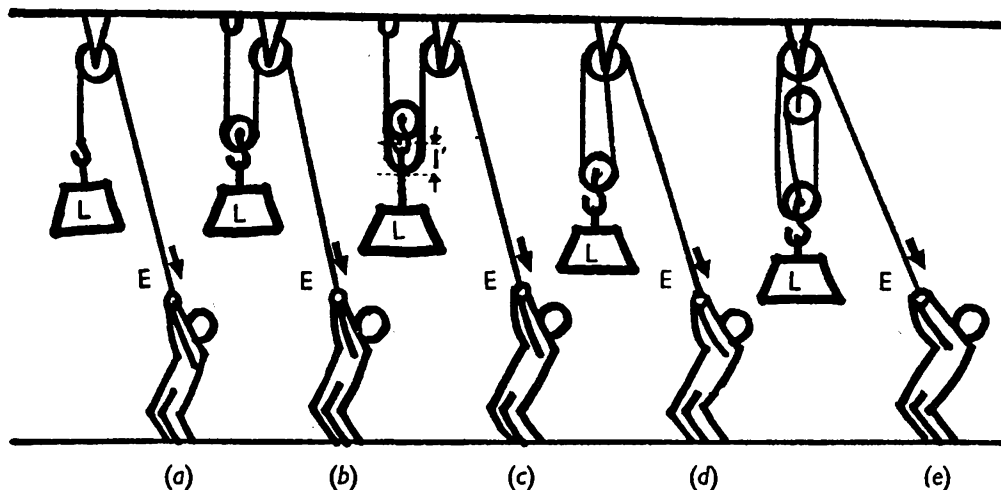


Fig. 191

### Kinetic energy

A moving car, planet or molecule has kinetic energy. The faster each moves the greater is its kinetic energy. In Orkney, one of the windiest spots in Britain, the kinetic energy of the moving air is used to drive wind turbines and generate electricity. Toy cars are powered by the kinetic energy of a flywheel which has been spun to a high speed. In Switzerland some buses have huge flywheels which are set going

when the trigger is pressed. *Name three types of energy into which this potential energy is changed when the pistol is fired.* (23)

If a rubber band is stretched, energy is again stored in it. We say that work has been done in stretching the rubber; that is, the energy supplied by our muscles has been changed in part into the potential energy of the stretched rubber.

When the *north pole* of one magnet is pulled away from the *south pole* of another, work is

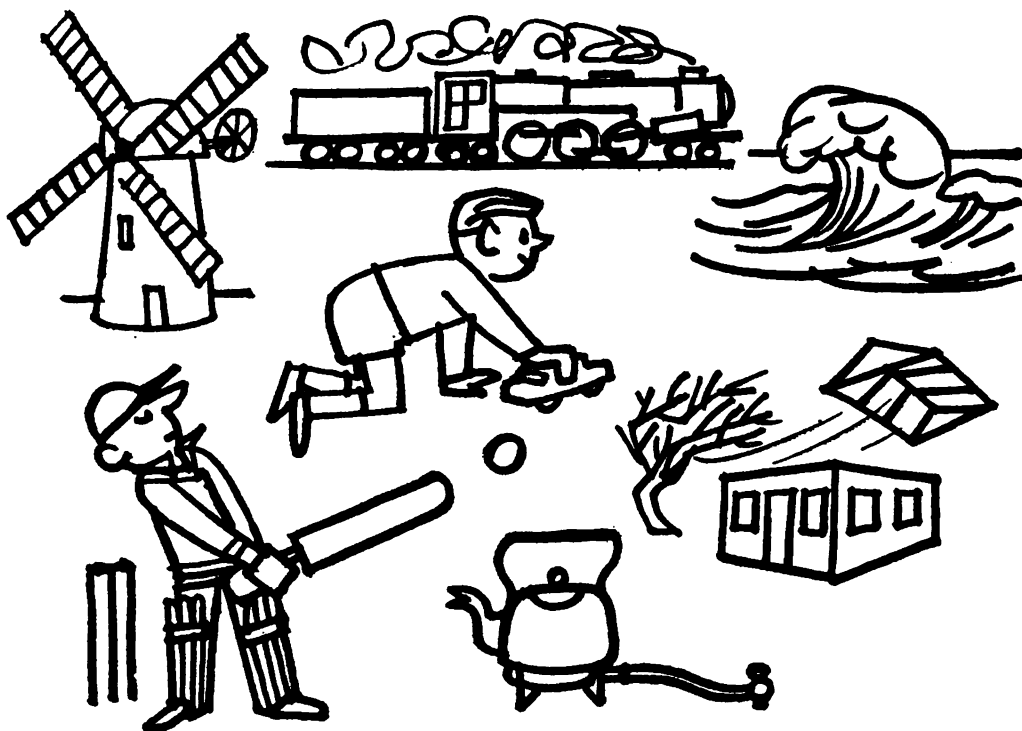


Fig. 192. Kinetic energy

by electric motors. The electrical energy is available at various bus stops and the energy stored in the flywheels keeps the buses going between stops.

Heat energy can usually be thought of as the kinetic energy of the higgledy-piggledy molecules. The temperature rises as the average kinetic energy of the molecules increases.

### Potential energy

When a toy pistol is loaded, energy may be stored in a compressed spring. It is released

done and energy is stored as magnetic (potential) energy. If the magnets are released they will fly together. *Why do they not move together if they are pulled more than a few inches apart?* (24)

A stone thrown into the air will come to rest when its kinetic energy has been completely changed into (a) heat, as it rubs against air molecules, and (b) potential energy, as it is moved away from the Earth. The potential energy is then changed into kinetic energy and heat as the stone falls.

The potential energy stored in sea-water when

the tide rises can be used to generate electricity. There are only a few places where the difference in level between low and high tide is great enough to be of much use. One such place is on the Rance Estuary in Brittany, where a tidal power plant has been built.

During the night, when less electricity is being used, the output from a power station can be

them together you are using energy. It is stored as electric (potential) energy. When you release the balloons they fly apart (kinetic energy).

**Experiment 13.6.** Take a large elastic band and touch your lips with it. Now stretch it *quickly* and again touch your lips (Fig. 194). Is the band warmer or colder? Release it *suddenly* and again test to see if it is now warmer or

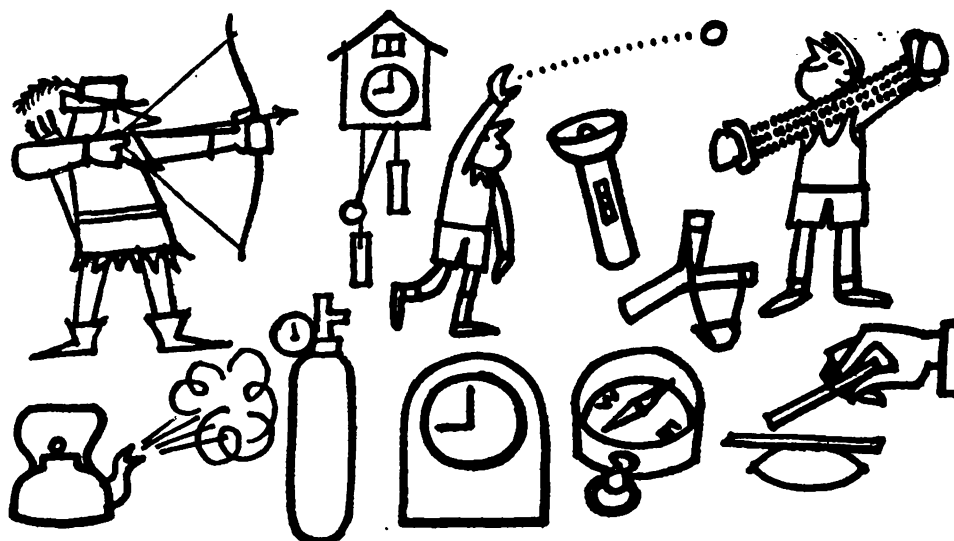


Fig. 193. Potential energy

employed to pump water up to a high reservoir. The water will then possess potential energy which can be utilised later to operate turbines and so produce electricity at a time when it is required. Examples of such 'pumped storage' are to be found in the Ffestiniog scheme in North Wales and in a similar scheme at Loch Awe in Scotland.

*What energy changes take place when (a) a ball runs down a hill, (b) you run along and then jump off a spring-board? (25)*

A charged polythene rod (negative) is attracted to a charged cellulose acetate rod (positive). If they are pulled apart work is done and energy is stored as electric (potential) energy.

**Experiment 13.5.** Charge two balloons by rubbing them with wool and hang them on nylon threads. What happens if you bring the two balloons together? As you pull or push

colder. Some of the work you did to stretch the band has been changed to potential energy and some to heat energy.

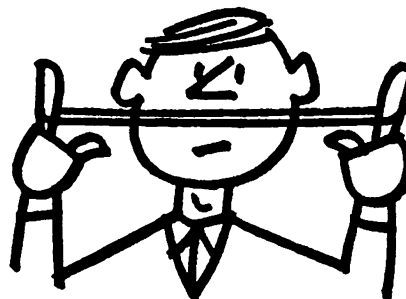


Fig. 194

### Latent heat

When boiling water (liquid) is heated still further it changes to steam (gas). The gas occupies about two thousand times more space than the liquid. This means that the gas mole-



cules must be very much farther apart than the liquid molecules. We have already discovered that liquid molecules attract each other strongly. How then can those molecules be torn apart? If work has to be done to pull the molecules apart the necessary energy must come from the heat energy being put into the boiling water. As the liquid molecules are pulled apart to form a gas they gain potential energy. This is given out in the form of heat energy when the gas changes back to liquid. This is why a burn from steam is much worse than a burn from boiling water, although the temperature of each may be the same. The heat taken in or given out when a substance changes state is called *latent* (meaning hidden) *heat*.

### Chemical energy

We may also consider chemical energy to be potential energy. Here is a picture which it may be useful to have when thinking about some chemical reactions.

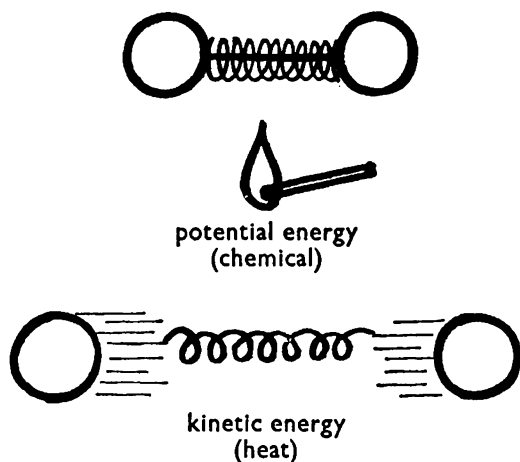


Fig. 195

Imagine two billiard balls held together by a thread through the middle of a compressed spring (Fig. 195). Potential energy is stored in the spring. If now you introduce a little heat energy with a lighted match and burn the thread the energy in the spring is released and the balls fly apart. Each ball has kinetic energy. The kinetic energy is, however, much greater than the small amount of heat energy fed in by the match.

Real chemical reactions are, of course, much more complicated than this simple picture. This model represents a chemical reaction in which energy is released when the bits fly apart as in an explosive. In most of the chemical reactions you will meet, however, energy is released when the bits come together, as they do, for example, when magnesium is burned in air.

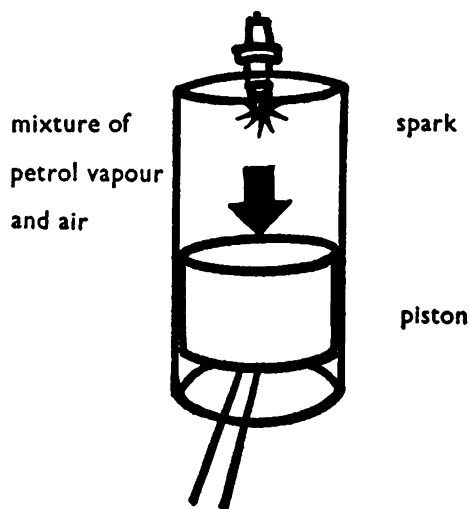


Fig. 196

Sometimes a little heat energy can spark off a chemical reaction which gives out a great deal of energy. In a car engine, for example, the heat from a tiny electric spark can cause the mixture of air and petrol vapour to burn (explode) and a tremendous amount of heat is released (Fig. 196). This heat energy in turn pushes the piston and drives the car (kinetic energy).

**Experiment 13.7.** Lay a metal plate on a tripod stand and heat it with a bunsen burner (Fig. 197). Now wrap the head of a match in heavy silver paper and place it on the metal plate. What energy changes occur?

In torch batteries and car batteries chemical energy is stored so that when required it can be changed into electrical energy, which may then be further transformed into heat, light, sound and movement. *Give examples of each*

of those four forms of energy coming from a car battery. (26)

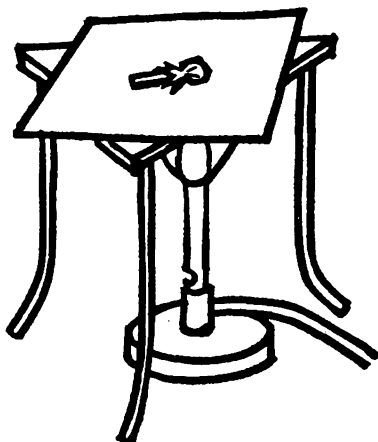


Fig. 197

### Combined kinetic and potential energy

Energy sometimes appears as a combination of both kinetic and potential energy. A pendulum is a good example of this (Fig. 198).

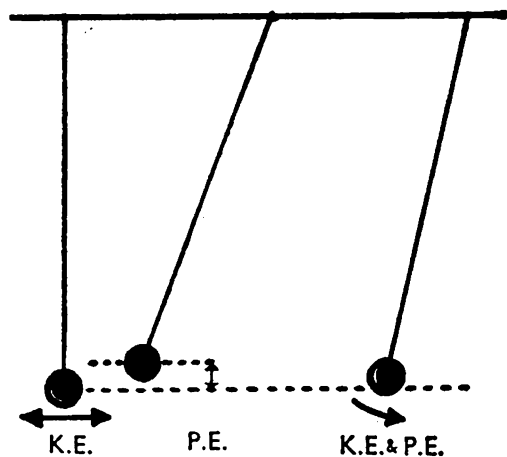


Fig. 198

When the pendulum is at the bottom of its swing it has kinetic energy. At the top of its swing it is not moving and therefore has no kinetic energy. All the energy is then stored in the form of potential energy. At every other position the pendulum has some kinetic and some potential energy.

**Demonstration 13.8.** If a flywheel (such as an old gramophone turntable) is attached to a coil of spring steel (Fig. 199) it will rotate to and

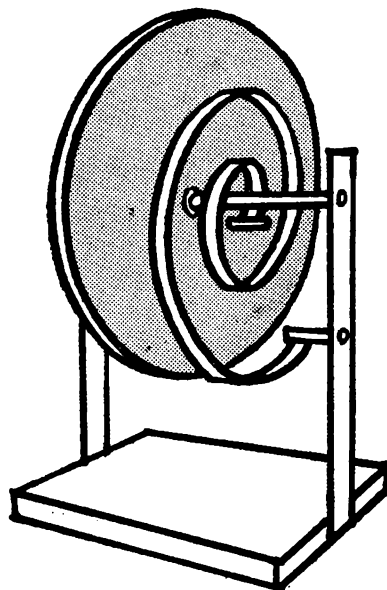


Fig. 199

fro. When will all the energy be in the form of potential energy? When will it all be in the form of kinetic energy?

**Experiment 13.9.** You can puzzle your friends with this obedient can which returns to you if you ask it at the right time!

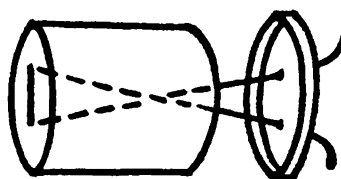


Fig. 200 (a)



Fig. 200 (b)

Pierce two holes in the base and the lid of the can and thread a piece of elastic through them as shown (Fig. 200 (a)). Hang a weight

over a thread at the point where the elastic crosses. Now close the lid and join the ends of the elastic (Fig. 200 (b)). Push the can along a level surface. It will return at least part of the way towards you. Can you explain its movement in terms of kinetic energy and potential energy?

**Experiment 13.10.**

(a) Study the motion of a ball-bearing going down a curtain rail. Into what kind of energy is the original potential energy of the ball finally changed?



Fig. 201

(b) Take a piece of cardboard, or hardboard, and bend it to form a hammock-shaped track as shown. Use two toy cars of the same size, one free-running and one with a flywheel motor. Start them together from the top of the track and explain the difference in their speeds.

Do they reach the same level on the opposite side? Explain.

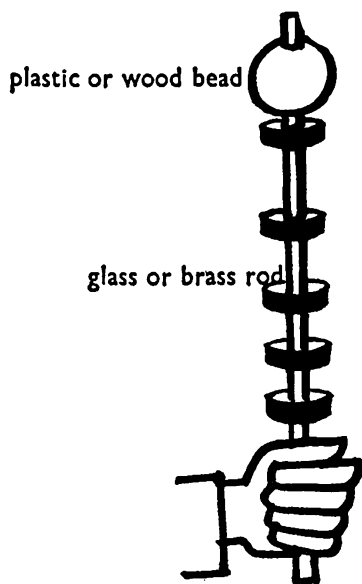


Fig. 202

**Experiment 13.11.** Place a number of small ring magnets on a vertical glass rod so that like poles are always next to one another (Fig. 202). Place a plastic bead on the top magnet. If the bead is now pressed down work is done and energy is stored in the magnetic field. When the bead is released it is raised against gravity. Explain what has happened to the energy stored in the magnetic field.

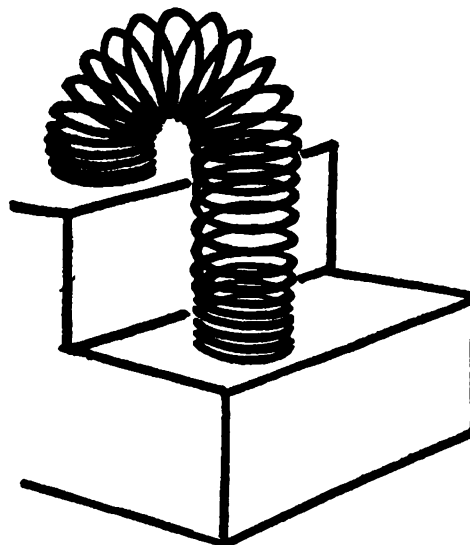


Fig. 203

**Experiment 13.12.** Watch a Slinky 'walking' down a flight of stairs! (Fig. 203). What forms of energy are involved here? (Suitable Slinkies are available from Griffin & George.)

Energy is sometimes sent out in waves. Sound waves combine kinetic energy of moving air molecules and potential energy of compressed or stretched air. Radiant energy such as the light and heat we receive from the sun comes as waves. It too may be thought of as a combination of both kinetic and potential energy. Radio and television waves are similar.

**Experiment 13.13.** Here is a simple experiment to show how radiation from the sun can be used to do mechanical work. Blacken the surface of a round flask with soot or matt black paint. Fix a balloon over the neck of the flask and place it in strong sunlight (Fig. 204). Can you explain the movement of the balloon?

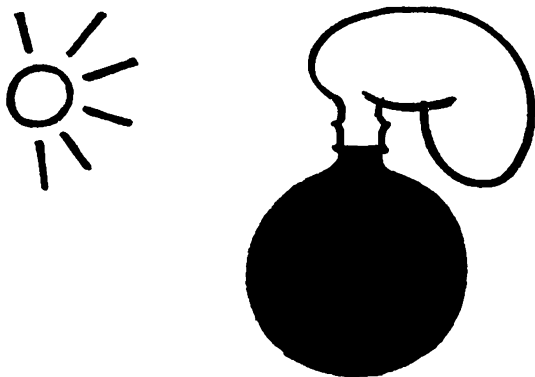


Fig. 204

## Energy transformations

We buy energy to do useful jobs for us. Modern civilisations use more and more 'canned' energy. This fact becomes obvious when there is an electrical power failure, a gas shortage or a petrol crisis. With the exception of electrical energy we buy energy in a chemical form. None of this energy is any use to us, however, in the form in which we buy it. It must be transformed. *Study the things illustrated in Fig. 205 and write a list of the kinds of energy obtained from each one of them.* (27) *What do you think*

*is the most convenient form of energy supply?*  
(28) *Why?* (29)

### Energy transformers

Here are some models of other types of energy transformers.

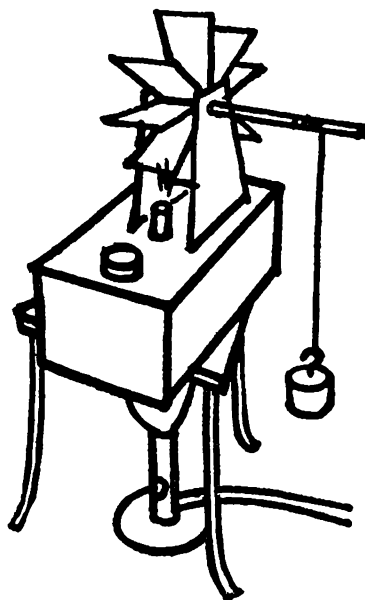


Fig. 206

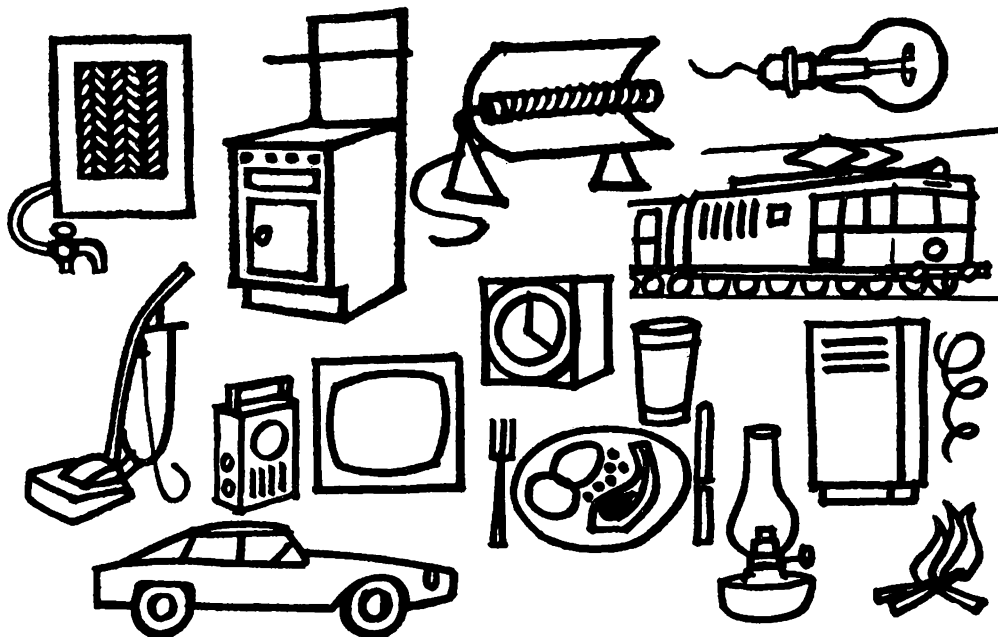


Fig. 205

### Demonstration 13.14.

(a) *Steam turbine.* Fig. 206 shows how heat energy can be changed to mechanical energy. Trace out the various energy changes that take place.

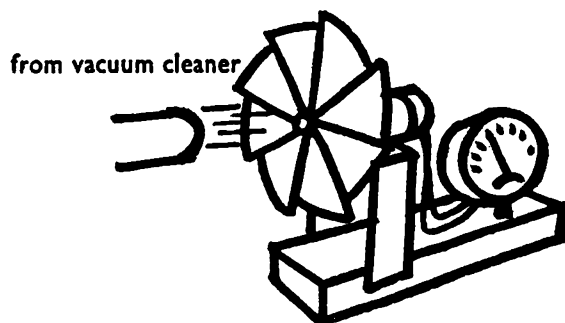


Fig. 207

(b) *Windmill.* A windmill can be used to generate electricity (Fig. 207). Small electric motors used to drive models make ideal generators. They cost about 4s.

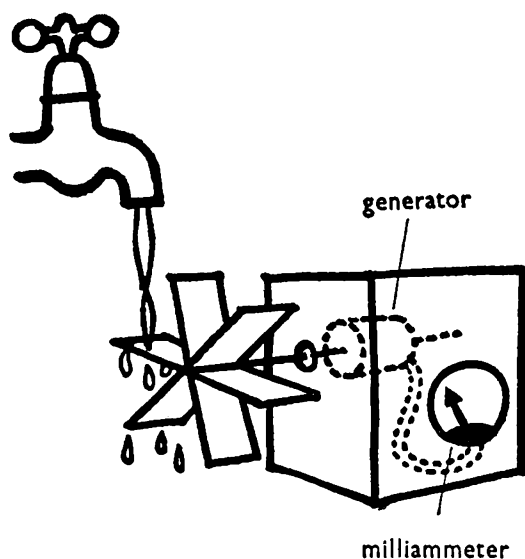


Fig. 208

(c) *Hydro-electric scheme.* Fig. 208 shows the potential energy stored in water being changed into electrical energy. Can you state all the energy changes involved?

(d) *Jet propulsion.* A syrup tin is ideal for this model (Fig. 209). Action and reaction are

equal and opposite. How many forms of energy can you find here?

(e) *Pile-driver.* A model pile-driver may easily be built from a glass or Perspex tube and

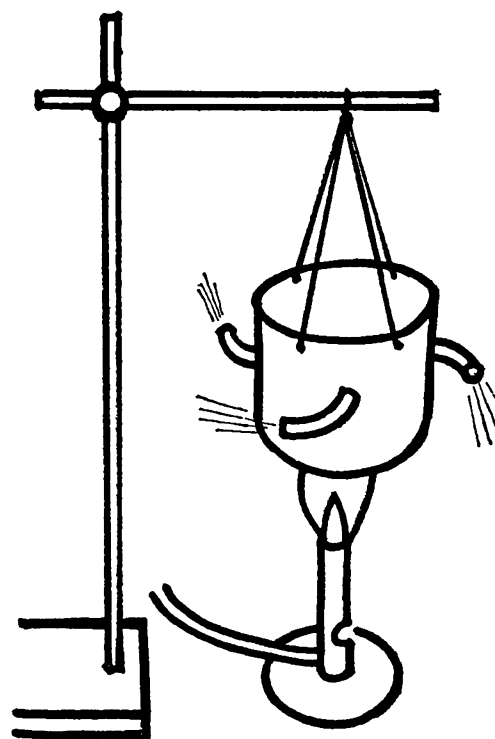


Fig. 209

a metal cylinder (Fig. 210). When the cylinder falls it knocks a nail into a piece of cork. What energy changes are taking place here? Replace the cork and nail by a compression balance, and find the maximum force exerted when the cylinder falls. Compare this force with the weight of the cylinder.

(f) *Car engine.* A model internal combustion engine was described on page 88. In it chemical energy is changed to heat energy and then to mechanical energy.

(g) *Electricity from the sun.* If an oxide layer is formed on a copper surface and then light is allowed to fall on this layer, a tiny electric current can be produced. This is called the photo-voltaic effect. It may be used to operate a meter as in the case of the exposure meter used by photographers (Fig. 211). Earth satellites use the sun's energy to operate solar

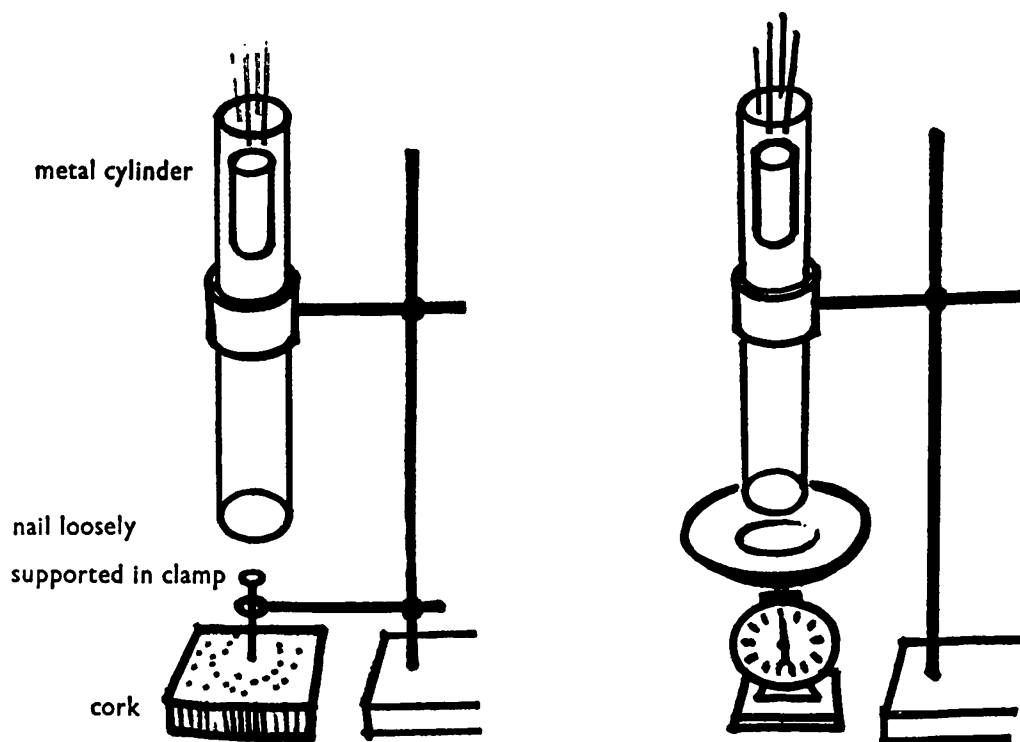


Fig. 210

batteries, which in turn supply electricity for the satellite's electronic equipment.

(h) *Mechanical energy from the sun.* The bunsen burner heats the water and changes it to vapour (Fig. 212). The vapour rises and is cooled. It then changes back into drops of

water which fall down the tube and are collected in a can. The outlet from the can is opened and

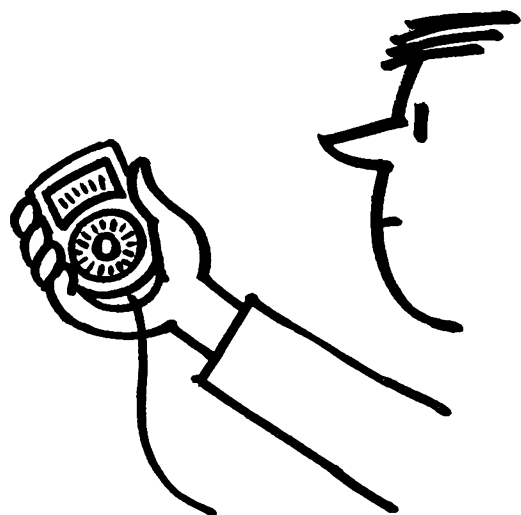


Fig. 211

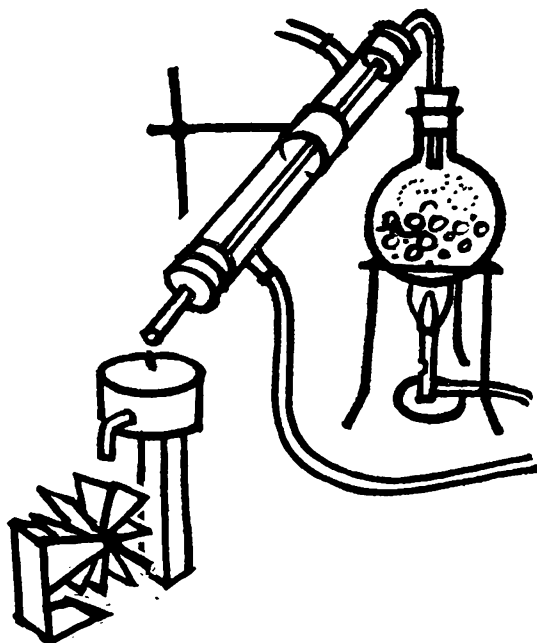


Fig. 212

the water drives a model turbine. Can you explain in detail how this model represents mechanical energy obtained from the sun?

**Experiment 13.15.** *Domestic heating from the sun.* Melt some sodium thiosulphate (hypo) crystals in a test tube by heating it gently in a bunsen flame. Place a thermometer in the hypo and allow it to cool. When the temperature reaches about  $30^{\circ}\text{C}$  drop in a hypo crystal and watch the temperature as the liquid solidifies. The change of temperature is so great that you can easily feel the difference by holding the test tube for a few seconds before and during solidification.

Experimental houses have been built which use this principle to heat them. During the day a salt is melted by the sun's heat and at night the salt solidifies and gives out its heat to warm the house. Perhaps such houses require rather more sunlight than we normally have in Britain!

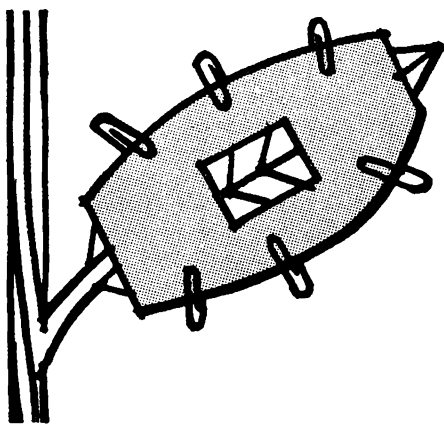


Fig. 213

**Experiment 13.16.** *Food from the sun.* Green plants build up sugar and starch from carbon dioxide and water. Some of the energy needed for the complicated chemical reactions which take place in the plant comes from the sun. Cover both sides of a leaf with black paper for two days (Fig. 213). Then cut out a small hole in the paper so that sunlight falls on one part of the leaf for a few hours. Remove the paper and, using a water bath, boil the leaf in industrial spirit until it is colourless. Now soak the leaf for a few minutes in a solution of iodine in potassium iodide. If starch has been formed

in the part of the leaf exposed to the light it should appear black.

## Whence and whither?

Where does it come from? Where does it go? Practically all our energy comes directly or indirectly from the sun. We depend upon it for our food, and our fuel. The energy stored in our corn flakes was originally the sun's energy which made the corn grow, perhaps in Canada, a year ago. The coal in our fires is releasing the sun's energy of 300,000,000 years ago, energy which made the forest trees that have slowly turned into coal. Nuclear reactions in the sun generate tremendous heat, and this in turn is radiated to the Earth. If the Earth is receiving so much energy from the sun, where does it all go? Why isn't the Earth getting warmer and warmer?

About a third of the energy reaching the Earth is immediately reflected by the atmosphere. Another third is absorbed by the atmosphere so that only about a third of the total radiation actually reaches the Earth's surface. As the Earth heats up, so it warms the air around it. The atmosphere then sends radiant energy back into space. Over a period of time the total energy received from the sun is equal to the energy sent back into space. You might therefore think that the energy we receive from the sun is not doing much good, since we lose it all again. This is not really so, however, because the energy we receive is of a better quality than the energy we give back. The quantity is the same but the quality is different. By 'quality' we really mean 'usefulness'. Electrical energy, for example, is useful, as it can be changed into so many different forms. Mechanical energy is also useful. It can be made to do many different jobs. What about the energy in an iceberg? There is more energy stored there than you are ever likely to need, but it is of little use to you. The poorest quality of energy is heat energy at low temperature, for it is difficult, if not impossible, to do anything with it.

Energy is like money; it is only useful because it can be changed into so many different things. If at the end of the week, you have no pocket

money left, you do not say, 'I don't want any more. I shall only spend it.' You realise that money is being useful only when it is being spent. Energy is only being useful when it is being transformed.

Every time energy is transformed, some of it is changed to poorer quality energy, so that it is never possible to return to the original state. If, for example, water flows down a hill and drives a turbine, which turns a generator, which produces electricity, which drives a motor, which operates a pump, which pumps the water back up the hill again, then the amount of water pumped up is less than the quantity which came down originally because at every energy-change heat was produced. This heat cannot be used to help pump the water up the hill again. It simply heats the atmosphere and is eventually radiated back into space.

This is the ultimate fate of practically every form of energy. As it changes from one form to another the quality of the energy becomes poorer and poorer, until eventually it ends up as heat at low temperature. You could in fact say that energy is something which sooner or later is changed to heat. All the energy stored in petrol, for example, ends up as low-quality heat.

*Name some of the other forms in which the energy could exist before it all ultimately changed to heat when petrol is used in a car engine. (30)*

## Production of heat

Here are a few simple experiments in which heat is produced from other forms of energy.

### (1) Heat from radiant energy

#### (a) Light

**Experiment 13.17.** Burn a hole in a piece of paper using a magnifying glass to focus the sun's rays. Why is it dangerous to leave bottles and broken glass lying around in the country?

In America and many eastern countries portable solar cookers are becoming popular. They resemble umbrellas and can be used to cook lunch out of doors (Fig. 214). The focusing of the sun's rays to produce heat is not,

however, really new. About 200 B.C. Archimedes is reputed to have set fire to the attacking Roman navy using a burning-glass made of many small mirrors.

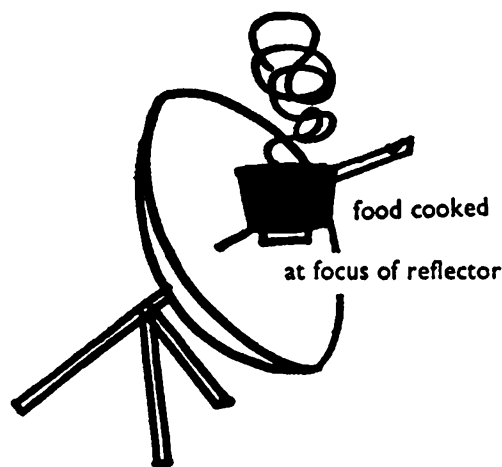


Fig. 214

**Experiment 13.18.** You can make a model of a solar furnace using a reflector from a car headlamp. Paint a thermometer bulb matt black and fix it at the focus of the reflector using a rubber stopper (Fig. 215). Watch the temperature change when the sun shines on the reflector.

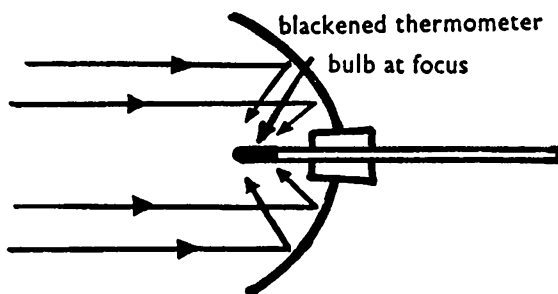


Fig. 215

#### (b) Infra-red radiation.

**Demonstration 13.19.** Place an infra-red lamp (for example a 250-watt Philips I.R. lamp) behind a large round flask filled with iodine dissolved in carbon tetrachloride (Fig. 216). The iodine cuts out visible light and allows infra-red rays to pass. Place your hand about



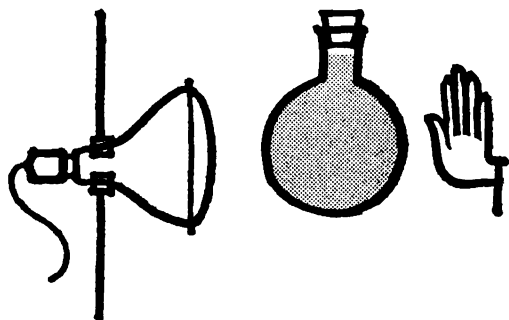


Fig. 216

three inches in front of the flask to detect the focused rays.

(c) Ultra-violet radiation.

**Demonstration 13.20.** Project ultra-violet radiation on to fluorescing objects such as minerals from the geology cupboard, clothes washed with detergent or objects smeared with Vaseline or painted with fluorescent paint. Invisible energy (ultra-violet) is being changed into visible energy (light). This light energy is, in turn, changed into heat energy. Ultra-violet radiation can harm your eyes. You should never look directly at an ultra-violet source.

(2) Heat from mechanical energy

**Experiment 13.21.**

(a) Hold a piece of metal against a rotating grindstone. What are sparks?

(b) Rub your hands vigorously together many times.

(c) Touch the point of a drill which has just been used to bore a hole in hard wood. Saw or file a piece of metal and see if heat is produced. Why are brake drums sometimes fitted with cooling fins?

(d) Make a thermocouple by twisting together the ends of iron and Constantan wires and connect the other ends to a sensitive microammeter, the iron to the positive terminal. Hammer the thermocouple and describe the energy changes which take place.

(3) Heat from electrical energy

**Experiment 13.22.** Connect a piece of fine fuse wire or a torch bulb across an accumulator.

What happens? Give several examples of heat being produced electrically.

(4) Heat from chemical reaction

**Experiment 13.23.** Strike a match and use it to ignite a piece of magnesium ribbon held in a pair of tongs. Name all the energy changes which take place. State three other chemical reactions in which heat is given out.

(5) Heat from other forms of energy

The heat produced by sound waves is too small and the heat produced by nuclear reactions is too great to be demonstrated in a school laboratory. Heat is, however, produced by both of those types of energy. In nuclear power stations heat from nuclear reactions produces steam, and steam turbines operate the generators.

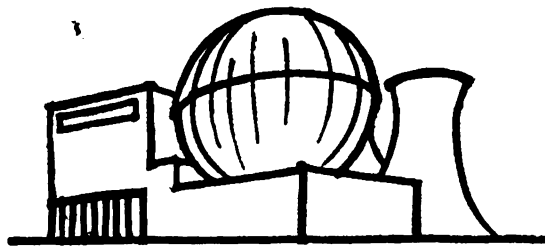


Fig. 217

**Energy from heat**

Although practically every kind of energy eventually turns to low-quality (cool) heat, high-temperature heat can be changed into many useful forms of energy.

In steam, diesel and petrol engines heat is changed to mechanical energy. Nuclear, coal- and oil-burning power stations produce electricity from heat. In an electric bulb the temperature of the filament is raised until it glows white and gives out light energy. At present scientists are developing new ways of changing heat energy into electrical energy. You can produce a small electric current yourself by heating two different metals in contact in a bunsen flame. *What is this arrangement called? (31) Draw the apparatus, showing how you would detect the current. (32)*

In Abidjan (French West Africa) the heat energy in the sea is used to drive turbines which produce electricity, and, in parts of Italy and

New Zealand, steam, which pours continually from holes in the ground, is also harnessed for this purpose.

## Visual aids

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Visual Publications issue three filmstrips suitable for the work of this section. They are *Energy and Man*, Parts 1, 2 and 5.

An excellent chart entitled 'Energy—key to all activity' is available from Esso.

Charts showing diagrams of nuclear power stations may be obtained from Nuclear Power and The United Kingdom Atomic Energy Authority.

# Suppliers

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